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LECTURES ON IRON-FOUNDING.

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LECTURES ON IRON-FOUNDING.

LECTURES ON IRON-FOUNDING.

BY

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PREFACE.

IN addition to the ordinary teaching in connection with the School of Metallurgy of the University of Birmingham, special short courses of lectures dealing with local industries have been arranged from time to time. These have been delivered in the evenings, and have attracted considerable audiences.

In the spring of last year, for the third time since the department was established in Mason College in 1885, the subject chosen was Cast Iron. There was no intention to publish these lectures when they were originally prepared, but so many requests were received for copies, not only from the audience, but also from distant parts, that, somewhat reluctantly, publication was at length decided on.

It is hoped by this means that those who attended the lectures will have an opportunity of going once more over the same ground, whilst the information will also be rendered available for a wider public. At the same time it is realized that the lectures will lose in publication the advantages of practical illustration at the lecture table. The form most suitable for popular explanation is also, at times, not that most fitted for a written statement. Hence, though the general scope of the lectures has been retained, opportunity has been taken to introduce some alterations and additions, which will, it is hoped, make the work more permanently useful.

In explanation of the scope of the lectures it may be added that the audience consisted chiefly of men who are actually engaged in the iron-founding and allied industries; to such an audience any detailed description of practical manipulation would have been superfluous, while they would, on the other hand, have found too much theoretical explanation tedious and difficult to follow.

A number of illustrations have been specially prepared for use in connection with these lectures, and I desire here to gratefully acknowledge assistance rendered in this direction by various friends. To Mr O. F. Hudson, Lecturer in Metallurgy in the University of Birmingham, I am indebted for the preparation of the micro-

photographs reproduced in Figs. 46 and 48 to 53, and also for reading the proofs. Mr J. Roberts kindly supplied the drawing for Fig. 20, and Mr J. T. Stobbs the photograph for Fig. 2. The British Westinghouse Co., Ltd., kindly provided drawings for Figs. 18 and 19; while Messrs Thwaites, Ltd., prepared a special diagram which has been reduced in Fig. 23. I am also under obligation to the proprietors of *Cassier's Magazine* for the blocks used for Figs. 9, 13, 28, and 29; and to Mr W. Jones for that employed for Fig. 27; while my thanks are specially due to Mr W. J. Keep for permission to use Figs. 34 to 38 and 40 to 45 from his volume on *Cast Iron*.

If practical men of the type which attended these lectures should find the earlier portion of this little book interesting, and the remainder of actual utility in their daily avocation, the desires of the author will have been fully realized.

THOMAS TURNER.

THE UNIVERSITY, BIRMINGHAM,
March 1904.

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LECTURE I.

VARIETIES OF IRON AND STEEL. EXTENDING APPLICATION OF CAST IRON. HISTORY OF CAST IRON. PRODUCTION OF CAST IRON. CHIEF IRON ORES. COMPOSITION OF IRON ORES. PHOSPHORUS PRESENT IN PIG IRON. PREPARATION OF ORES. CALCINATION. GENERAL ARRANGEMENT OF A BLAST FURNACE PLANT.

LECTURES ON IRON-FOUNDING.

LECTURE I.

Varieties of Iron and Steel.

EVERYONE connected with the manufacture of iron and steel is aware that iron is commonly met with in three forms:—namely cast iron, wrought iron and steel; and that the properties of these varieties differ so much that there is frequently less difference in physical properties between separate metals, such as nickel and cobalt, or tin and lead, than there is between, say, white cast iron and wrought iron, or grey cast iron and tool steel. These remarkable differences in properties are not due to any variation in the iron itself, but are dependent upon the proportion of other constituents which are present in or with the iron. These constituents can scarcely be regarded as impurities, in that they are necessary for the production of the particular qualities which are desired.

Cast iron may be regarded as the iron smelter's crude product. It is the cheapest form in which iron is met with in commerce. It is, relatively, easily fusible and brittle, and contains a large proportion of foreign substances, the total amount of impurities seldom being less than 5 % of the whole, while it frequently amounts to 8 or 10 %, and, in special cases, to an even higher proportion.

Wrought iron, on the other hand, is tough, and has a fibrous structure. While it welds easily, it is only fusible at a very high temperature. Speaking generally, it is the purest commercial variety of iron, and usually contains about 0·25 % of total impurities.

Steel is a material of intermediate chemical purity, which is now made in so many forms as to make a simple definition somewhat difficult. But it may be conveniently divided into two kinds, one of

which, known as "mild steel," is produced in large quantities in a molten condition, and is used where tenacity and ductility are required. The foreign elements in this variety are usually under 1 %, carbon and manganese being the most important constituents. The other, and more expensive variety of steel, is manufactured in smaller quantities, usually in crucibles, and it combines with moderate fusibility the remarkable properties of hardening and tempering which are so valuable in the production of tools of all kinds. Steel of this kind usually contains from ·5 to 1·5 % of carbon.

The following table gives the approximate proportion of carbon contained in steel used for various typical purposes, and illustrates the considerable differences met with on analysis. These variations in composition lead to the development of very distinctive physical properties, and it is important that the engineer or workman should select steel which has a suitable composition for the purpose in view.

Carbon in Steel used for various Purposes.

	Per cent.
Wire, sheets, smith's work	·06 – ·15
Bridges	·2
Boiler plates	·25 – ·30
Rails and tyres	·30 – ·50
Springs	·5
Pressure dies	·75
Wood chisels, sets, etc.	·875
Cold chisels	1·00
Large cutters, dies, etc.	1·125
Cutters, drills, etc.	1·25
Hard files	1·375
Razors	1·50

Extending Applications of Cast Iron.

When in 1886 I first delivered a course of lectures in Birmingham on cast iron, it was anticipated by many, that, owing to the rapid development of steel foundry practice, the demand for cast iron would rapidly diminish, and that iron-founding would soon become a thing of the past. On that occasion, however, I ventured to quote with approval, from the address of the late Mr Jeremiah Head, as president of the Institution of Mechanical Engineers, in which

reasons were given for anticipating a continued and extended use of the cheaper material. These anticipations have been fully borne out in the interval that has since elapsed.

Cast iron possesses, among other advantages, the following properties, which render it especially suitable for foundry work.

On account of its cheapness, castings can be produced in iron at lower prices than in any other metal, while, owing to its abundance, it is less liable to suffer considerable fluctuation in price. It can also, for these reasons, be readily obtained in all parts of the civilised world. Its easy fusibility also tends to allow of its ready melting and manipulation, while the expansions[1] which take place during solidification, and subsequently, enable it to take a sharp impression of the mould. It possesses sufficient tensile and transverse strength for the majority of ordinary applications, while its crushing strength is higher than that of any other material used in construction. It requires no annealing, hence time is saved, as compared with steel, and a casting can be produced immediately if required, either for a special order, or in case of breakage. Castings in iron have finer and smoother surfaces than those produced in steel. Iron castings are less liable to rust than wrought iron or ordinary steel, especially if the skin is retained. Further, when used for bearing surfaces, cast iron wears well, while the additional weight of the cheaper material which can be used is often an advantage for the bed-plate or foundation of an engine, or of a large machine tool.

From the above considerations it may be reasonably anticipated that, despite the ever increasing application of steel, the uses of cast iron are likely to be considerably extended rather than to show any important diminution.

History of Cast Iron.

The production of cast iron is now the first stage in all modern processes of iron and steel manufacture, and pig iron is the most abundant variety of iron in commerce. It was not, however, the form of iron first made, nor indeed was iron the material originally used by man for his tools and implements.

Prehistoric man employed tools and weapons made of stone, flint

[1] Molten iron, from which graphite separates, expands at the moment of solidification. Subsequently, during cooling, a further separation of graphite takes place, interrupting the regular rate of contraction by momentary expansion.

being largely employed for such purposes. This early period in the development of the race lasted for a very considerable period, and is conveniently divided into three stages.

(1) Eolithic, in which the stone implements were very roughly shaped, chiefly by chipping.

(2) Palæolithic, in which there was a greater variety of instruments, and these were more perfectly shaped.

(3) Neolithic, in which still more highly finished hammers, chisels, and other tools were produced in stone, and *polished*.

During the latter part of this stone age, bronze was introduced. This was, in the first place, merely an impure copper, hardened by sulphur, arsenic, iron, or other impurities, more or less accidentally introduced. As the bronze age progressed, the value of tin was fully recognised, and the composition of the later examples of bronze was much the same as that of the gun-metal of the present day.

About the beginning of the historic period, or perhaps somewhat earlier, iron was introduced. It was always made by a process of simple reduction from the ore, the product being wrought iron. By a slight modification of the simple process so employed, steel could be made as readily as wrought iron, and was so produced on a considerable scale. The Romans were familiar with both iron and steel, and produced these materials in large quantities during their occupation of Britain.

With the revival of knowledge towards the close of the dark ages, more iron was required and furnaces of increased size were adopted. No doubt in some of these large "bloomeries" cast iron was at first accidentally produced. It was believed by Lower that cast iron was made in Sussex about 1350, but the exact date of its practical application for foundry work is unknown, though this would appear to be certainly not later than 1490, its earliest application being on the continent of Europe. Its use rapidly spread into England, so that in September 1516 a large iron gun called "The Basiliscus," which weighed about 10,500 lbs., had been cast in London.[1] At the Tower of London there are still preserved two large cast iron guns which were brought over from Ireland in the reign of Henry VIII.

All the iron produced at this period was made by the use of charcoal, and the growing scarcity of fuel crippled the iron trade of the United Kingdom, while the industry still flourished on the continent, where charcoal was more abundant.

[1] Viscount Dillon, *Archæologia*, Vol. LI. Part I., page 168.

Iron was first smelted with coke, made from pit-coal, in Staffordshire, by Dud Dudley, in the reign of Charles I., but the process was revived and brought into practical use by Abraham Darby at Coalbrookdale, in Shropshire, about 1730, and this process made available, for the purpose of the iron-master, the greater part of the enormous coal supply of Great Britain, and rendered possible the developments which followed. These included the introduction of steam-blowing engines about 1770, and the application of the hot-blast by Neilson in Scotland in 1829. The latter invention was shortly afterwards followed by improved blast furnace shape, and increased capacity, particularly in Staffordshire, which county was in 1850 the leading iron producing centre in the world.

The opening up of the Middlesboro' district about this time, with the subsequent introduction of much larger furnaces, and fire-brick regenerative hot-blast stoves, led to an enormously increased production, and Cleveland became the chief centre of the iron industry; but the development of the Connellsville coke region in Western Pennsylvania, and of the Hematite ~~magnetic~~ iron ore deposits of Lake Superior, led to so great an increase in the American iron trade, that in 1890 the production of the United States for the first time exceeded that of the United Kingdom. The subsequent developments and improvements in the blast furnace practice in the United States, and the opening up of the mines of soft, rich, easily reducible iron ore in the Mesabi range, combined with the enormous demands of a rapidly developing country and a protective tariff, have led to unprecedented production, so that the output of pig iron in the United States in 1903 was no less than 18,000,000 tons, as against a production of 8,500,000 tons in the United Kingdom.

During the nineteenth century many wonderful advances attracted public attention, such as the substitution of the stage coach by the express train, and of the sailing ship by the ocean liner, while the old, crude methods of signalling were replaced by the telegraph or telephone. But perhaps in no direction was more progress made than in connection with the metallurgy of iron and steel. In blast furnace practice alone the output per furnace, during the century, was increased fully a hundredfold, while the fuel consumption per ton of iron was reduced to one-fifth of that previously employed. It is not too much to say, that apart from this remarkably increased production and economy in the manufacture of iron, much of the great material

progress which will always be associated with the Victorian era would have been impossible.

Production of Cast Iron.

As the iron-founder in his daily business is called upon to use different varieties of iron for particular purposes, and, partly with the object of obtaining a better product, and partly on account of variations in supply, he seldom confines himself to a single brand of iron, it is important that he should have some information as to the sources from whence the iron he uses is obtained, and the methods by which it has been manufactured. Such knowledge will allow of more intelligent foundry mixing, and frequently also of the production of a better product at reduced cost. But as the iron-founder is generally only a user and not a producer of iron, it will not be necessary to enter into any minute detail as to the process whereby cast iron is made, a general outline being sufficient for present purposes.

Iron Ores.

The primary consideration which affects the quality of pig iron is the character of ore from which it has been produced. Some ores contain little phosphorus, while others carry much more of this constituent. Some ores, again, are more silicious or sulphurous than others, while some contain more manganese. With normal furnace working the proportion of the elements which enter into the composition of the iron naturally varies largely with the amount originally present in the ore.

There are in various parts of the world large mineral deposits, rich in iron, which cannot be utilised for iron manufacture. As examples of these may be mentioned deposits of pyrites, the proportion of sulphur in which renders such ores quite unsuitable for iron making. Another familiar example is seen in the basaltic rocks, which, though often rich in iron, contain this element in the form of a silicate, which is difficult to reduce on the large scale. In view of the cost of equipment and the enormous output of modern plants, the deposits, to be valuable to the iron smelter, must be of very considerable magnitude. The ore must also be rich in metallic iron, free from any excess of injurious impurities, and

easily reducible in the blast furnace. The materials which satisfy these conditions may be grouped under two heads:—

(1) Oxides of Iron.

(2) Carbonates of Iron.

The oxides include a considerable variety of ores which are known either as magnetites or hematites; while the carbonates include spathic ores and clay iron-stones.

Oxides of Iron.

The oxides of iron may be conveniently divided into two classes:—

(1) *Anhydrous Oxides*, which consist of oxide of iron associated with what may be regarded as merely accidental impurities or gangue. These ores are known as magnetites and red hematites.

(2) *Hydrated Oxides*, in which the oxide of iron is associated with more or less combined water in addition to the mineral gangue. These ores include various forms of reddish and brown hematite.

Magnetites consist essentially of magnetic oxide of iron, the formula for which is Fe_3O_4, and if perfectly pure this would contain 72·4 per cent. of metallic iron. It is widely distributed, and has been worked from the very earliest periods. It occurs in two chief forms —in the massive condition, and in the finely divided state.

Massive magnetite is mined in the North of Europe and in the Lake Superior district. In the finely divided condition it occurs on the surfaces of older deposits, and as sands in various parts of the world. The enormous deposits of iron ore in the Mesabi[1] range are now the most important single source of supply in the whole world. In this region, the magnetic ore is so soft that it can be readily removed with steam shovels, by which it is placed in steel hopper cars, each of which holds about fifty tons (see fig. 1). It is then transported in specially constructed steamers across the great lakes, and reloaded on waggons, by a mechanical hoisting apparatus, to be taken for smelting to Pittsburg, or elsewhere, as required. These deposits were only opened up in 1894. But the ease with which they can be mined, their extent, and their easy reducibility, are such that the

[1] This is sometimes spelled Mesaba. It appears there are at least twenty-five ways of spelling this name, and it is questionable which of these is nearest to the original Indian pronunciation.

present output is nearly 10,000,000 tons per annum, or something like three-fourths of the total supply of the Lake Superior district, and there is every reason to believe that the deposits are of such magnitude as to ensure an ample supply of ore for generations to come.

Red Hematite consists essentially of ferric oxide (Fe_2O_3), and, when pure, contains 70 per cent. of metallic iron. It is usually red in colour, though denser varieties are sometimes very dark, but they all possess a red streak, and form a red powder if crushed in a mortar. These ores, on account of their freedom from phosphorus, were formerly the chief source of supply for Bessemer purposes. In the United Kingdom they occur chiefly in the Cumberland district.

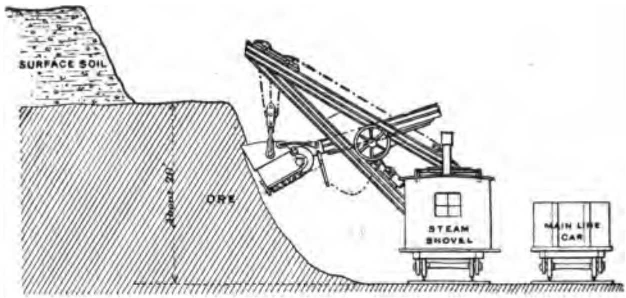


FIG. 1.—Steam Shovel digging iron ore, Mesabi district, Minn., U.S.A.

The red hematites of the United States are less pure than those of Cumberland, and are now relatively less important, owing to the extended use of magnetites in recent years.

Hydrated Oxides.

Brown hematites, as obtained from Spain, are generally of special purity, while those of the United Kingdom and of the rest of Europe are usually phosphoric.

The proportion of water which may be present in hydrated oxides of iron varies considerably, being lowest in the reddish-brown hematite, or rubio ores, which are largely imported from Spain. An intermediate amount is met with in ordinary brown hematites, such as occur in Northamptonshire and in the Rhenish provinces; while the highest proportion occurs in the bog or lake ores, used to a moderate extent in Sweden and elsewhere.

Carbonates.

These ores consist chiefly of ferrous carbonate ($FeCO_3$), which, when perfectly pure, contains 48¼ per cent. of metallic iron. It occurs, usually associated with carbonate of manganese, in considerable quantities in Styria, where it has been worked from the earliest historical periods.

In the United Kingdom two forms of impure carbonates are used. The first is the **clay ironstone** of the coal measures, which occurs in West Yorkshire, Staffordshire, and South Wales. From this class of ore is made some of the best forge and foundry iron that the world produces, but unfortunately the supply is relatively small. The other variety is the **Cleveland Ironstone**, which occurs in the N.E. of England, and is met with in the Lias formation. The deposits are of considerable magnitude, and the ore is of uniform quality, the percentage of metallic iron being, however, lower than in any of the ores previously considered, while it is also phosphoric. A special variety of clay iron stone which is impregnated with more or less carbonaceous matter is known as "**blackband**," and this is worked in the West of Scotland, and in North Staffordshire.

The table on page 12 will illustrate the chemical composition of the chief ores which have been enumerated above.

From these figures it will be seen that there are great differences in the composition of typical ores. These variations arise from the proportion and state of oxidation of the iron; the amount of manganese—which affects the hardness and crystalline character of the product; the phosphorus—which affects its strength; and the volatile portion, consisting of water and carbon dioxide—the amount of which determines the preliminary treatment which may be necessary before the ore is smelted in the blast furnace.

The impurities which are thus present in iron ores may conveniently be divided into three kinds:—

(1) Those which are volatile, and can be more or less completely removed by calcination,—*e.g.*, water, carbon dioxide, sulphur.

(2) Those which are not volatile, but which can be removed in the slags during smelting—*e.g.*, silica and alumina.

(3) Those which cannot be removed either by calcination or in the slag, and the whole of which therefore pass into the pig iron. Of these the most important is phosphorus. The following table illustrates the approximate proportion of phosphorus

	Swedish Magnetite.	Mesabi Magnetite.	Red Hematite, Cumberland.	Red Spanish Ore, Bilbao.	Forest of Dean Hematite.	Brown Spanish Ore.	Northampton Brown Hematite.	Styrian Spathic.	Staffordshire Clay Ironstone.	Cleveland Ironstone.	Blackband, Scotland.
Ferric oxide (Fe_2O_3), .	65	85	90	70	90	71	65	...	0·5	3	2·5
Ferrous oxide (FeO), .	25		...	...	...	...	...	50	47	40	41
Manganous oxide (MnO),	...	...	...	1	...	...	0·5	10	2	1	1
Carbon dioxide (CO_2),	...	...	...	3	...	...	...	38	30	25	26
Silica (SiO_2), . .	10	6	6	7	1	8·5	13	...	10	8	7
Alumina (Al_2O_3), .	...	2·5	1	1	...	1·5	3	...	5	7	3
Lime (CaO), . .	...	0·75	1	5	...	1	variable	2	2	7	2
Magnesia (MgO), .	...	0·5	...	1	...	...	...	...	2	4	1
Phosphoric anhydride (P_2O_5)	0·03	0·22	0·04	0·03	0·07	0·04	1·3	0·04	0·4	1·6	0·5
Water, . . .	...	5	...	12	9	18	14	...	1	3·4	1
Organic matter, .	...	...	...	...	...	...	...	..	trace	trace	15

which is met with in pig iron smelted from the ores named. It is well for the founder to remember that, generally speaking, the phosphorus content of pig iron made from a certain ore, or ore mixture, is approximately constant, although there may be considerable variations in the proportion of other elements present.

Phosphorus present in Pig Iron.

I. *From Non-Phosphoric Ores.*

	Phosphorus per cent. in the Pig Iron.
Swedish Magnetites	0·01 – 0·06
Cumberland Hematite	0·04 – 0·06
Spanish Hematite	0·04 – 0·06
Forest of Dean Hematite	0·07
Lake Superior Magnetites	0·08

II. *From Moderately Phosphoric Ores.*

Purple ore	0·10
Lake Superior Magnetites	0·15
South Staffordshire Clay Iron Stone	0·40 – 0·60
Leicestershire Brown Hematite	0·60
Scotch Blackband	0·60
American Red Fossil (Alabama)	0·65
North Staffordshire Blackband	0·80 – 1·00

III. *From Phosphoric Ores, etc.*

Rhenish Brown Hematites	about 1·00
Northamptonshire Brown Hematites	1·00 – 1·50
Derbyshire	1·30 – 1·50
Cleveland	1·10 – 1·75
Lake and Bog Ores	about 2·00
Staffordshire Part Mine	1·00 – 2·00
Cinder Pig	up to 3·50

Preparation of Ores.

In many districts the material as extracted from the mine has to pass through a preliminary treatment before it can be employed in the blast furnace. Such operations may, in exceptional cases, include

washing, to separate the ore from lighter earthy impurities. With dense ores, like massive magnetite, sizing is sometimes necessary; while material which is rich in sulphur, in the form of iron pyrites, is usually exposed to the weather for some months, so that by the absorption of oxygen from the air, the pyrites may be converted into ferrous sulphate, which is washed out by the falling rain.

Clay ironstones are also frequently weathered, so that, by the action of moisture and frosts, the associated shaly matter disintegrates and crumbles away from the harder lumps of good ore.

A special method of preparation of magnetic ores containing phosphorus is also adopted on a considerable scale. In this case the ore is first crushed to a powder and then passed through a magnetic concentrator, which divides the material into two streams, one being magnetic oxide of iron, while the other contains the greater part of the associated gangue and of the phosphoric acid. By this process it is possible to make iron of Bessemer quality from relatively inferior ores. Though magnetic concentration is conducted on a very large scale in America at the present time, the process has not made the progress that appeared probable a few years ago. This is owing to the discovery of other deposits of considerable purity, which are so soft as to be readily and very economically worked. The magnetites of Norway and Sweden are, however, now being magnetically treated, and it is hoped by this means to provide a considerable addition to the available supply of the Bessemer ores of Europe.

Calcination.

Until the end of the nineteenth century much the greater part of the iron ore which was smelted was first calcined, but the enormous increase in the amount of soft magnetite obtained from the Lake Superior district has rendered calcination relatively much less important than was previously the case. But as the majority of the ores used in the United Kingdom are still calcined, some reference must be made to this important preliminary operation.

The objects of calcination are:—

(1) By the removal of carbon dioxide, water, carbonaceous matter and other volatile or combustible substances, to concentrate the ore so as to lessen the cost of transport, and to enable the process of reduction in the blast furnace to proceed more regularly.

(2) To as far as possible eliminate the sulphur from the ore.

(3) To convert any ferrous oxide which may be present into ferric oxide, so as to prevent the formation of "scouring" slags due to imperfect reduction in the blast furnace.

The method adopted for calcining varies, partly according to the locality, and chiefly according to the kind of ore which has to be treated. Brown Hematites already contain ferric oxide and are calcined merely to eliminate combined water. They are usually treated in heaps, more or less enclosed by walls, in the neighbourhood

FIG. 2.—Calcining Black-Band Ironstone in Open Heaps in North Staffordshire.

of the mine or open workings from which they are extracted. The ore is mixed with about 10 per cent. of its weight of rough slack, and combustion, when started at one end of the heap, gradually proceeds through the mass until the whole is dry, and its colour is changed from brown to red.

Blackbands contain sufficient carbonaceous matter to enable them to be calcined without any additional fuel. They are usually stacked in open heaps in the neighbourhood of the mine, such heaps being about thirty yards long, eight yards wide, and about six feet high.

During calcination the ore decreases considerably in volume, owing to the elimination of the carbonaceous matter and of the carbon dioxide originally present in the ore. The change in bulk is readily seen in the accompanying illustration (fig. 2), which shows the method of calcination adopted in North Staffordshire. Combustion is in progress in the middle of the heap. The portion behind the man has

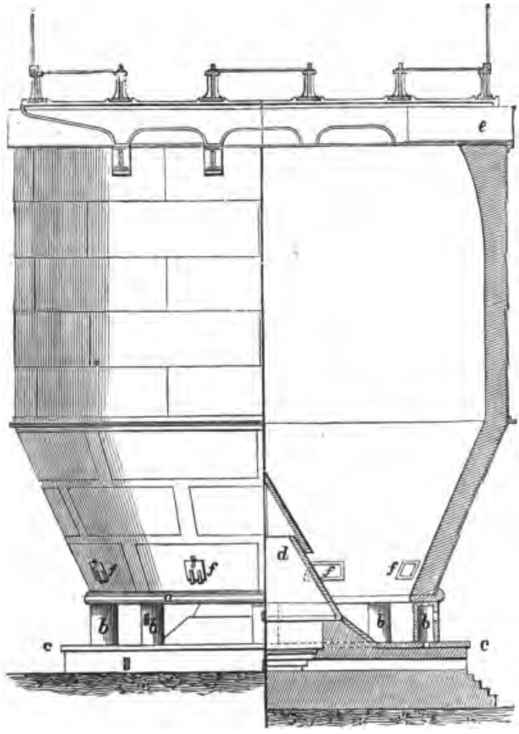


FIG. 3.—Cleveland Calciner.

not yet become ignited; while, on the other side, roasting is completed, and the bulk considerably diminished.

Clay ironstones and other carbonate ores are now almost invariably calcined in kilns, as when so conducted the process is much more under control, while the cost for labour, fuel, and space is considerably lessened. The form of kiln most commonly adopted is that known as the Cleveland calciner, which is illustrated in fig. 3. The floor of

the kiln is covered with cast-iron plates (*c*), on the centre of which is fixed a cast-iron cone (*d*), about 8 feet high, with a base 8 feet in diameter; the object of this is to cause the descending materials to pass outward, and so to assist in the regular descent of the charge. A number of short cast-iron columns (*b*), rest upon the bottom plates, and support a cast-iron ring (*a*), upon which the kiln itself rests. The ore and fuel are brought in trucks running on the two lines of rails shown at the top of the calciner, and the trucks are arranged to allow of the materials readily falling out when the bottom of the truck is released. In the lower row of plates are a number of openings (*f*), to which are attached doors by means of which the draught can be regulated and any obstruction removed in case of irregular working.

Such a calciner is capable of dealing with about 1,000 tons of ore weekly, and consumes about 1 cwt. of coal, in the form of rough slack, per ton of ore.

The ore having been thus prepared, or being, as previously explained, in many cases already in a suitable condition, has now to be smelted in the blast furnace for the production of pig iron.

General Arrangement of Blast Furnace Plants.

On account of the enormous scale on which modern smelting operations are conducted, a site of considerable area is necessary for the proper laying out of a blast furnace plant. The ground should be, as far as possible, level, and should also be firm, so as to allow of good foundations, while a locality should be chosen which is advantageously placed for obtaining supplies of ore and fuel, and for the distribution of the product when made. With a view to ensuring these advantages there is a growing tendency in the United Kingdom for blast furnace plants to be erected near to the sea coast, so as to save railway carriage.

In the United States the blast furnace plants are, generally speaking, erected near to the fuel supply, while in Germany the chief works are in the neighbourhood of the Rhine; the object being in each case the same—to reduce the cost of transportation.

In addition to the space required for the ordinary smelting operations it is advisable to provide sufficient room for the storage of stocks, in order to meet any difficulty due to a temporary stoppage of supplies. In those American works which depend upon Lake Superior ores, specially large stock-yards are provided, as the great

lakes are frozen for five months each year, and sufficient ore must be stored during the summer to supply the furnaces throughout the winter. Hence stock-yards capable of storing hundreds of thousands

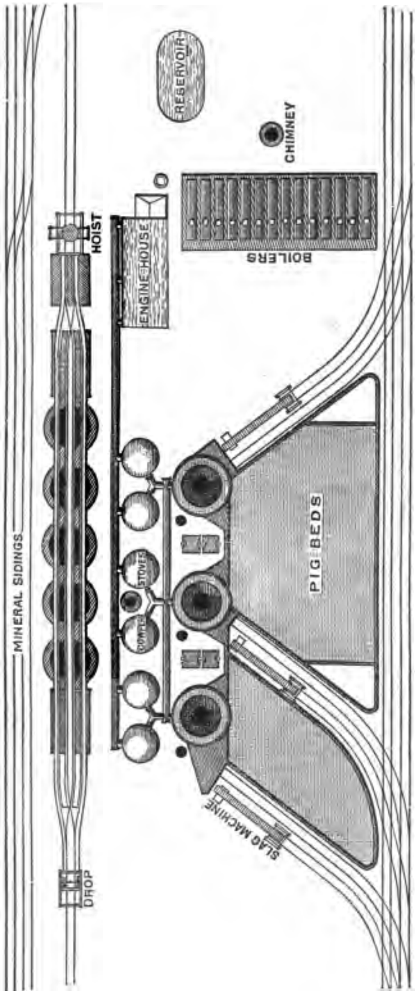


FIG. 4.—Arrangement of Blast Furnace plant, Cleveland.

of tons of iron ore are provided, and the ore is stocked in these by special unloading and distributing appliances, worked by large overhead traversing cranes or tramways.

The general arrangement of a blast furnace plant in the Cleveland district is shown in fig. 4. The ore to be treated is brought into the works by the mineral sidings shown, and passes by means of the hoist to the top of the calciners, five of which are shown in the plan. The waggons, when emptied, pass away by means of the drop, while the ore after passing through the calciner is taken to the blast furnaces, three of which are shown in the illustration. In connection with each blast furnace are two hot-blast stoves for heating the air which is supplied by the blast engine situated in the engine-house. The iron produced by the blast furnace is cast in pig beds in front of the furnace, and is carried away on the lines of rails shown, while the slag is disposed of by a machine by which it is granulated, and in this form it is now generally used for ballast or for the production of slag cement.

In this plant the fuel used is coke, but in some cases raw coal is employed, and it is then found advantageous to provide a condensing and washing plant, so as to extract the ammonia and tar from the gases before they are used for firing the boilers. Plants for dealing with part of the gases from coke furnaces are coming into pretty general use, as the gases when collected and cleaned can, without difficulty, be used in gas engines for supplying blast or for many other purposes around the works.

In fig. 5 is given a section of the fairly typical arrangement of a portion of a Southern American blast furnace plant erected about 1890. It will be seen that the furnace is of what is called the cupola type, having comparatively thin walls which are steeply inclined, and that it is provided at the top with a cup and cone charging arrangement so as to allow of the collection of the gases, which are taken to the stores and boilers by means of the wide pipe or downcomer, to the bottom of which a dust catcher is attached. To each furnace three fire-brick stoves with separate chimneys are provided. The blast is conducted from the stoves to the furnace by means of the blast pipe shown, and enters the furnace through twyers placed around the hearth, while water blocks are introduced in the inclined sides or boshes of the furnace in order that the lining may be kept cool and the shape preserved. In this plant the stock-yard and pig-beds are covered, while the waste gases from the furnace are conducted along an underground flue. It will be noted that no calciners are provided in this plant.

The general arrangement of a modern American blast furnace

plant of considerable size will be understood by reference to the plan of the celebrated Edgar Thompson Works, near Pittsburg, Pa., which is given in fig. 6. This plant includes nine blast furnaces, and in addition, two other furnaces have been recently erected on an adjoining piece of land, not included in this plan. The furnaces are known by the letters from A to I, and with the exception of A, which makes spiegel, and consequently has a smaller output, they all produce pig iron of Bessemer quality. The furnaces are arranged in pairs, each pair being provided with separate boilers, while there is a separate blowing engine to each furnace. As the

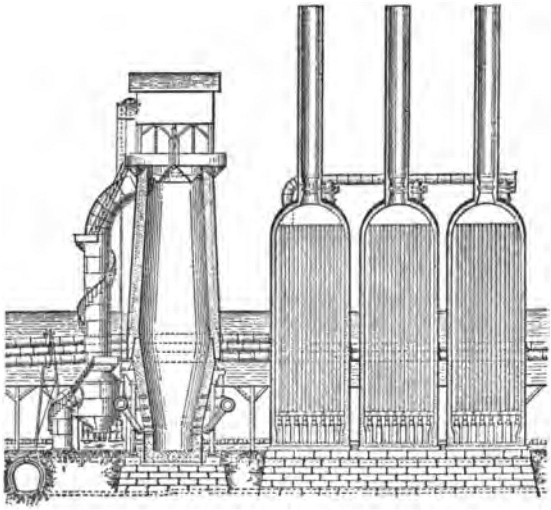


FIG. 5.—Section of Blast Furnace, Alabama, U.S.A.

ore used is chiefly obtained from the Lake Superior district, and is rich and free from moisture and carbon dioxide, calciners are not required, but large stock-yards are provided. Suitable hoisting arrangements and railways are arranged for handling the ore, and for dealing with the pig iron and slag produced by the furnaces.

Although it has been possible in this brief survey only to give a very general outline of the sources of supply and properties of iron ores, and of the arrangements of a modern iron works, it is hoped that sufficient has been said to render intelligible the somewhat more detailed description of the process of iron smelting, which will form the chief part of the subject-matter of the second lecture.

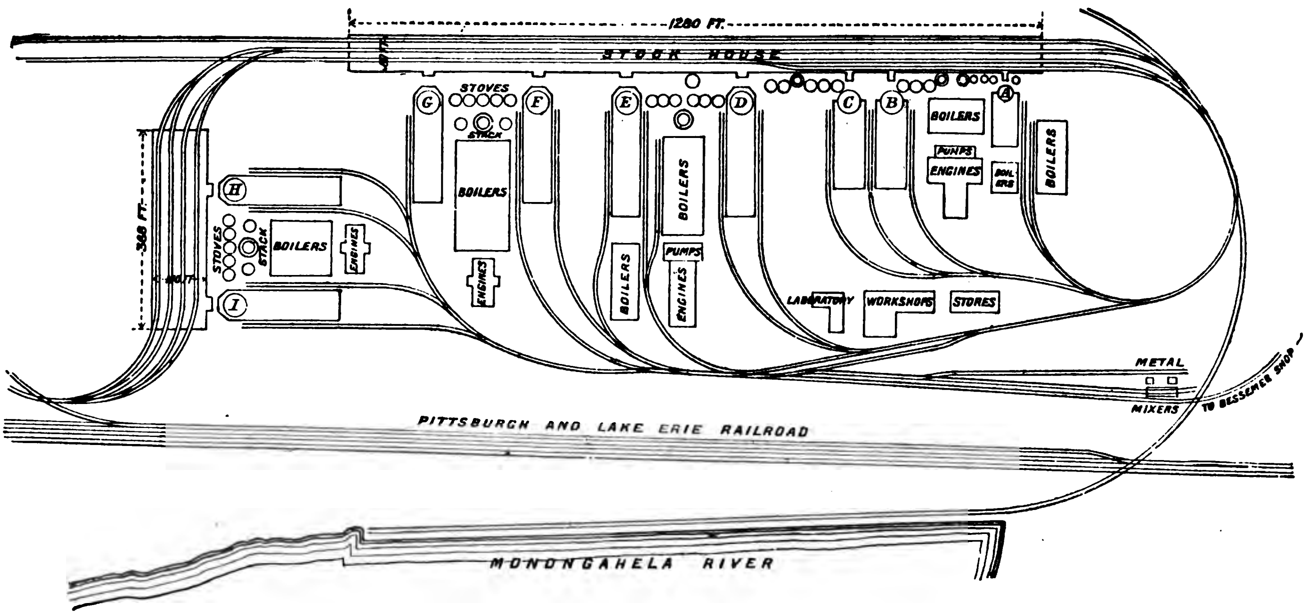


FIG. 6.—Plan of Edgar Thomson Works, Pittsburg, Pa.

LECTURE II.

THE BLAST FURNACE. MATERIALS EMPLOYED. REACTIONS OF THE BLAST FURNACE. CHARGING THE BLAST FURNACE. THE BLAST USED IN THE BLAST FURNACE. TAPPING. PRODUCTS OF THE BLAST FURNACE. WASTE GASES. CINDER. CAST IRON. GRADING PIG IRON. CONNECTION BETWEEN GRADING AND CHEMICAL COMPOSITION. DENSITY. UNRELIABILITY OF FRACTURE AS A TEST OF QUALITY.

LECTURE II.

The Blast Furnace.

In the previous lecture an account was given of the sources of supply of the chief iron ores, together with an outline of the general arrangement of a blast furnace plant. We have now to consider somewhat more in detail the methods adopted by the iron smelter for the production of pig iron for foundry use and other purposes.

The internal shape and construction of an ordinary Cleveland blast furnace is shown in fig. 7, which is taken from a paper by Sir B. Samuelson.[1] The furnace consists of a large cylinder made of plates of wrought iron or mild steel, and rivetted together so as to form an outer shell which rests on a ring, which in turn is supported on cast-iron pillars. The outer shell is lined with fire-brick slabs, while the furnace is closed at the top with a cup and cone arrangement to allow of the withdrawal of the waste gases by means of a downcomer not shown in the fig. The upper part of the interior of the furnace is called the throat. Passing downwards from it, through the main portion or body of the furnace, we come to the inclined sides or boshes, and thence to the hearth where fusion takes place, and at the bottom of which the metal accumulates beneath a layer of molten slag. Such a furnace would be about 85 ft. high, and have an internal capacity of 30,000 cubic feet and a maximum diameter at the boshes of 28 ft. and at the hearth of about 8 ft. The blast enters through six twyers at a temperature of about 1,450° F., and a pressure of some 5 to 7 lbs. on the square inch. The output of such a furnace would not much exceed 500 tons of grey pig iron per week, while 750 tons of slag would also be obtained. The ore used in its original state contains only about

[1] *I. and S. Inst. Jour.*, 1887, vol. i. p. 91.

temperature of the ascending gases, with the result that there is a considerable amount of regenerative action in the furnace, and this effect contributes largely to an economical production. The heat which is required for reducing the ore and melting the metal and slag, together with the additional heat obtained by the utilization of the waste gases, accounts for the profitable employment of about 75 per cent. of the calorific power which is theoretically available, a result which is obtained in no other manufacturing operation conducted on a large scale. The efficiency of a regenerative reverberatory furnace seldom reaches 20 per cent., while it has been shown by Colonel Cubillo, that the efficiency of the puddling furnace is only about 3 per cent. of that theoretically possible, while the wind furnace employed for melting metal in crucibles is still less efficient. The extraordinary efficiency of the blast furnace has led to its adoption for the preparation of cast iron, as the first step in all the important processes for the production of iron and steel, and at present there appears to be little likelihood of the blast furnace being superseded by any other appliance.

Reactions of the Blast Furnace.

As direct methods of observation are impossible, other methods have been adopted with the object of ascertaining, as far as possible, the progress of the reduction and the nature of the chemical changes which take place. Among these may be mentioned the classical researches of Bunsen and Playfair, who studied the composition of blast furnace gases, at different heights, by inserting a tube into the furnace and collecting the combustible products obtained. Reference should be made also to the experiments of Ebelmen and of Tunner, who enclosed the materials to be examined in a strong iron box, which was constructed so as to be permeable to the furnace gases, and was then allowed to descend with the charge into the furnace to the desired depth, when it was withdrawn by means of chains and the materials were examined.

A comparison of these results with those obtained by Sir Lowthian Bell in his studies of the changes which take place during the reduction of Cleveland ironstone, enables us to see that the character of the reduction varies somewhat according to the nature of the ore and the kind of fuel which is employed; the reduction being nearly complete in a Cleveland furnace by the time the charge has

descended through the first quarter of the height, while, when charcoal is the fuel used in the furnace, reduction takes place at a relatively higher temperature, and the charge descends about half way down the furnace before any considerable reduction begins.

As the Cleveland furnace is usually considerably higher than one employing charcoal as fuel, it follows that the zone of principal reduction is usually about 60 ft. above the bottom of the hearth in a Cleveland furnace, but only about 20 ft. high in a charcoal furnace; hence the period of heat interception is much longer in a Cleveland than in a charcoal furnace. The fuel consumption is, however, slightly less, and the proportion of carbon dioxide in the gases distinctly greater in the charcoal furnace, results which are no doubt connected with the nature of the reaction, and the position in the furnace where the principal reduction occurs.

The reactions which take place in a coke blast furnace may be conveniently divided into two classes; first, those which are essential for the production of heat and the reduction of the ore; and, secondly, those which are more or less variable or accidental, according to the particular materials which may be employed, or the special product which is desired.

The first class of reactions are exothermic, or heat-producing, and in their simplest form may be divided into two portions and represented as follows:—

(1) When the heated air enters the blast furnace it is immediately converted into carbon monoxide, the reaction being

$$2\ C + O_2 = 2\ CO.$$

It is worthy of note that the reaction thus taking place in the hearth of the blast furnace is quite different from that with which we are familiar in a gas producer, a cupola, or an ordinary fire. In these cases the carbon is first burned to form carbon dioxide, and this after it is formed reacts with more carbon to produce carbon monoxide, thus—

$$C + O_2 = CO_2 \text{ and } CO_2 + C = 2\ CO;$$

but while carbon when burned at a comparatively low temperature produces carbon dioxide, the condition is altered when the temperature is raised, since carbon dioxide is dissociated at a high temperature with the production of carbon monoxide and oxygen.

and from the stock-yard, or from the car direct, as required, to the bottom of the automatic charging apparatus, and hence into the furnace top. The usual form of automatic charging apparatus as at present employed consists of a double line of steeply inclined rails, supported on a frame work of rivetted steel, and passing from the charging hoppers on the ground level to a suitable position above the furnace top. On these lines run two skips made of steel plates, and arranged so that the descent of one skip serves to counterbalance the ascending weight of the other, so that only the weight of the load has to be raised. By an apparatus of this kind, electrically driven,

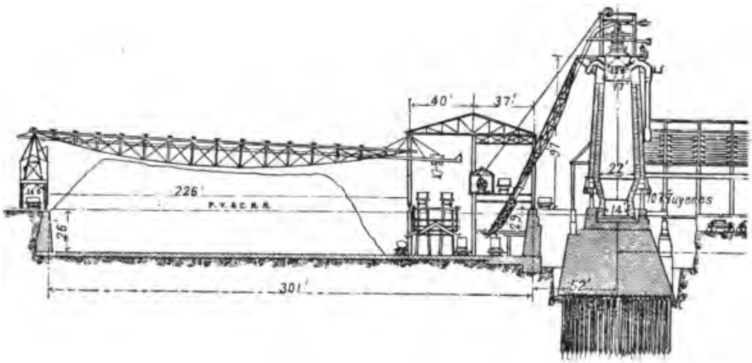


Fig. 8.—Section showing method of handling ore at Blast Furnaces, Duquesne, Pittsburg, Pa.

it is possible for one man remaining at the bottom of the furnace to charge the whole of the materials necessary for the production of the large output of a modern furnace. In order to allow of the gas being collected and utilized as usual, it is found necessary with an automatic charging apparatus to provide a double cup and cone arrangement, as shown in fig. 9.

The Blast used in the Blast Furnace.

The air used for the combustion of the fuel in the blast furnace was originally supplied by means of bellows worked by manual labour, and simple appliances of this kind are still used in India and elsewhere. Such simple forms of apparatus were gradually replaced by larger bellows driven by water power, and subsequently by the

steam engine. For many years beam engines were used for this

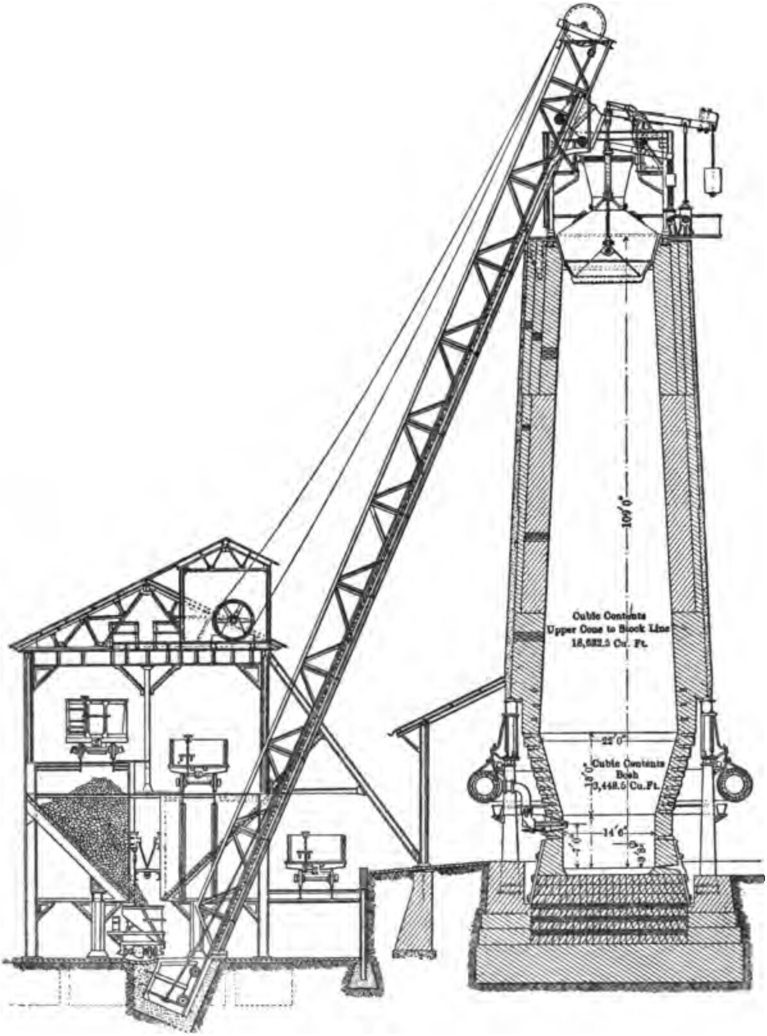


FIG. 9.—Modern American Blast Furnace, showing automatic charging apparatus and double cup and cone.

purpose. Modern blowing engines now, however, are of two principal types—vertical and horizontal. A pair of vertical direct acting

blast engines with fly-wheel are represented in fig. 10. Later forms of engines of this type have two cylinders, so as to allow of expansive working, and it is customary in American practice to

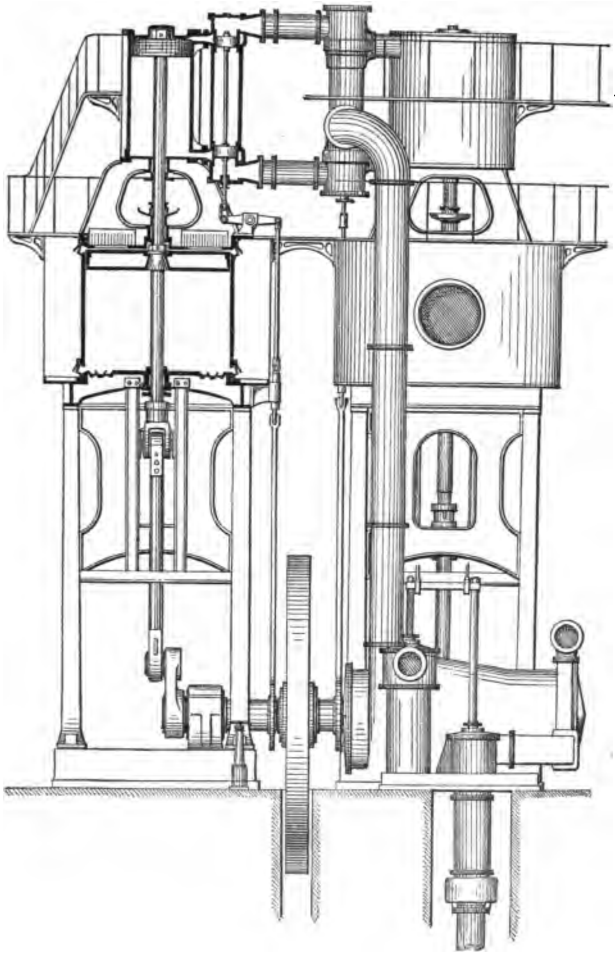


FIG. 10.—Vertical Direct-acting Blast Engine (Half Section).

provide a pair of such engines for each blast furnace. Horizontal gas engines are now made capable of generating upwards of 1,000 horse-power for the purpose of compressing air for use in the blast

furnace, and of these a number are in use in the United Kingdom and Germany.

The blast is now almost universally heated in fire-brick regenerative stoves, of which two patterns are well known—the Cowper and Whitwell; but there are many variations of the fundamental principles involved. The general arrangement of a blast furnace supplied with a pair of Cowper stoves is shown in fig. 11, from which it will be seen that each stove consists of a shell of wrought iron or steel plates, some 65 ft. high, with a dome-shaped roof, and with a circular flue extending from the bottom to the top, while the rest of the cylinder is filled with fire-bricks. The stoves are used alter-

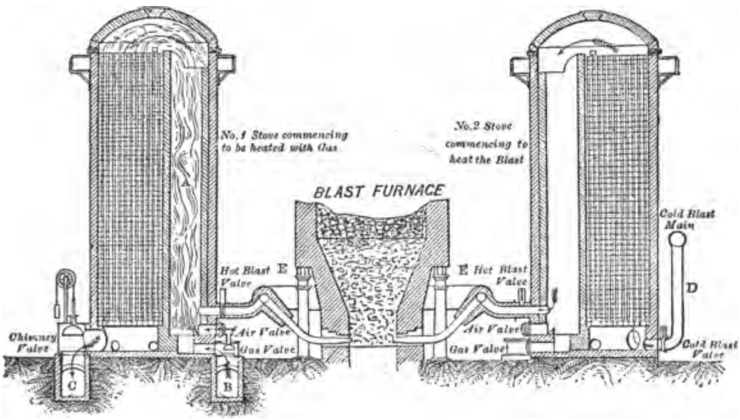


FIG. 11.—Furnace with Cowper's Hot Blast Stoves. Scale about 40 feet to an inch.

nately, the waste gases being burned in one stove, to heat the brick-work, while the cold air is being passed through the other stove, in the reverse direction, so as to heat the blast. From the stoves the air is conveyed through blast mains lined with fire-brick to the twyers by which it enters the furnace. So long as cold blast was employed these twyers were of iron and were provided with sheet iron nozzles; but with increased blast temperature it was found that iron twyers burn away very rapidly. Water-cooled twyers were therefore universally adopted. In American practice bronze water-cooled twyers are found to give excellent results, as they require but little repair or attention. In the United Kingdom, either Scotch twyers, which consist of coiled wrought iron pipes, embedded in a conical

pipe of cast iron, or water-cooled open twyers, which were first introduced by F. H. Lloyd in 1876, are generally used (see fig. 12). Recently, suction twyers have been adopted by Mr Foster of Darlaston (Staffs.), and these are stated to last longer and to give less trouble than the ordinary type.[1] The water for cooling these twyers is drawn by suction, instead of being forced under pressure, with the result that any leakage can be more quickly perceived, while leaks are frequently filled up and stopped by particles of slag and other

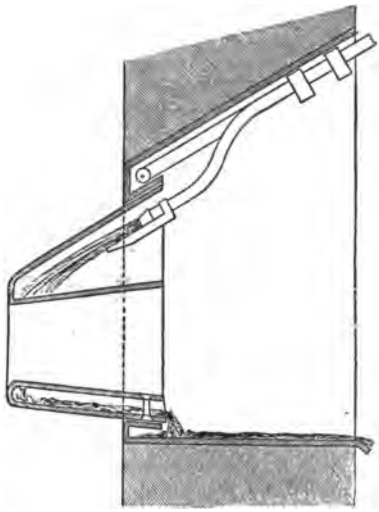


Fig. 12.—Water-cooled Open Twyer.

matter drawn from the interior of the furnace by the suction employed.

Tapping.

From what has been before said it will be seen that the whole of the material which is introduced into the blast furnace in the solid state is removed as a fluid,—either as gas in the form of an addition to the weight and volume of the blast passing through the furnace, or as molten slag or iron at the bottom of the hearth. Under ordinary working conditions, no solid material is taken from the blast furnace. As the metal and slag trickle down together into the hearth they separate, on account of their difference in density, the

[1] *I. & S. Inst. Jour.*, 1902, vol. i. p. 79.

lighter slag floating on the surface of the heavier iron. This proceeds until the slag reaches a predetermined height, when it is either tapped off from time to time or, more usually, allowed to flow off continuously through a water-cooled cinder hole. The iron still continues to accumulate in the hearth, and it is either tapped off, as required, if molten metal is employed, or, at regular intervals, if it is cast into pigs in the sand bed. The latter is the more usual practice.

Products of the Blast Furnace.

The three fluid products of the blast furnace, viz., the gaseous effluent from the top of the furnace, the slag and the metal obtained in the hearth, may now be conveniently considered in order.

I. Though the **gases** which pass off from the top of the blast furnace are commonly called "waste" gases, such a title is becoming more a misnomer every year. They were originally allowed to burn to waste at the furnace top, but experiments were made as early as 1814, with the object of utilizing some of the heat. In 1845, Bunsen and Playfair called attention to the high calorific value of blast furnace gases, and in the same year J. P. Budd obtained a patent for heating the blast in stoves by means of the combustion of waste gas. Budd was so successful and far-seeing that he anticipated what has been regarded in some quarters recently as quite a novel idea, when in 1848 he wrote as follows:—"It would appear to be more profitable to employ a blast furnace, if as a gas generator only, even if you smelted nothing in it, and carried off its heated vapours by flues to your boilers and stoves, than to employ a separate fire to each."

The increased economy of modern engines and stoves has permitted the whole of the boilers to be fired and the blast to be heated by the combustion of the waste gases from the furnace; and, particularly when raw coal is used, there is frequently a considerable surplus available for other purposes. The gases from raw coal, if cooled, yield ammonia equivalent to about 30 lbs. of commercial sulphate per ton of coal used. The value of this more than pays for the cost of its extraction. Such gases, when properly freed from dust, are admirably suited for generating power in gas engines. The gases are, in actual practice, constantly varying in composition, but the following analyses may be regarded as fairly typical of their

composition by volume, with the three kinds of fuel generally employed:

	Fuel Used.		
	Coke.	Charcoal.	Bituminous Coal.
Carbon monoxide (CO), .	25	19·5	28·0
Carbon dioxide (CO_2), . .	12	12·5	8·6
Nitrogen, ...	59	63·5	53·5
Hydrogen, ...	2	2·5	5·5
Marsh gas, ...	2	2	4·4

II. The **slag** or "**cinder**" obtained in iron smelting is usually about equal in weight to the metal made, the variation being from about 15 cwt. to 30 cwt. of slag per ton of pig iron. The slag consists essentially of a double silicate of alumina and lime, together with more or less excess of free lime, the object of the latter being the removal of the sulphur from the charge so as to obtain a grey pig suitable for foundry purposes. Slags obtained when making a strong or forge iron are usually themselves strong and compact, and are suitable for road-making, ballasting, and similar purposes; but blast furnace cinders obtained when making an open grain or foundry iron are sometimes so rich in lime as to spontaneously fall to pieces by slaking in the air after a brief exposure. Unsightly heaps of slag in various parts of the country bear testimony to the fact that the definition of slag as "the smelters' refuse," which was formerly adopted in metallurgical text-books, was at that time correct. So many applications have in recent years been found for this material, however, that, in the United Kingdom at any rate, the tendency would appear to be rather for the heaps to diminish than to increase. Among the chief uses may be mentioned, reclaiming of waste land; erection of sea walls and breakwaters; road-making (where the traffic is not heavy); production of slag cement, slag bricks and slag wool; for railway ballasting; for filter beds for sewage treatment; and for various other purposes. The number of applications which have been suggested, or which are in actual operation in connection with the various bye-products of the iron smelter, have also in recent years become so important that there are not wanting enthusiasts

who predict that, before long, the tables will be turned, and the combustible gases, the chemical products, and the slag will be the main sources of income, while the cast iron obtained will itself become the bye-product.

III. Turning now to this remaining product of the blast furnace, in which the iron-founder is more particularly interested;—the molten **metal** which accumulates in the bottom of the hearth is, as already mentioned, sometimes tapped off into ladles for use in the fluid state in the steel works, or for foundry purposes, if there is a foundry attached to the furnace. The more usual plan, however, is to run the metal into pigs in sand moulds, made in a pig-bed in front of the furnace. Pig-beds in the United Kingdom are usually in the open, but in the United States they are generally covered with a light roof, though open at the sides. In modern works, where there

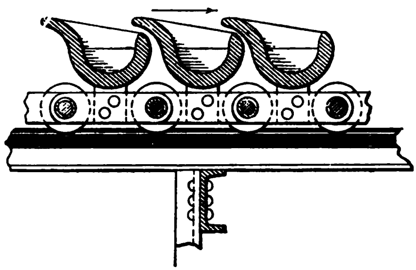


FIG. 13.—Section through the Moulds of the Uehling Pig Iron Casting Machine.

is a large output, it has been found advantageous to employ casting machines for dealing with the slag and pig iron respectively. Of these machines at least three kinds have met with some amount of success, but the form which is best known is that introduced by Uehling. It consists of a series of iron moulds, a cross section of which is shown in fig. 13. These moulds are arranged side by side, and are actuated in such a manner as to produce the effect of a continuously revolving band or belt, the upper stretch of which conveys the metal from the receiving to the discharging end. The fluid metal is tapped from the furnace into ladles, from which it is poured into the moulds, after these have been coated with a thin layer of refractory material. During its onward passage in the mould the metal is water cooled, and is ultimately discharged into trucks from the upper extremity of the revolving band, just as the moulds are in the act of passing over the end

wheel of the machine and beginning their downward and backward journey.[1]

Pig iron cast in sand always retains a certain amount of sand upon its surface, and an allowance for this is made by the seller. The amount of sand, however, varies very much according to circumstances, and the sand, when introduced into the cupola, leads to the use of more flux and more fuel; so that, other things equal, pig-iron cast in machines is to be preferred to that which has been cast in sand. On account of the closeness of grain of machine cast iron, such metal is looked upon with some suspicion by the iron-founder; but, since any closeness due to the sudden cooling in casting machines is entirely removed during subsequent remelting, the objection is one which is likely to disappear as chemical analysis is more commonly employed in connection with the iron-foundry.

Grading Pig Iron.

The pigs when cast in sand are of a ∪ section, and are usually about 5 feet long and weigh about 1 cwt. each. The blast furnace manager generally knows beforehand what is likely to be the character of the metal which is in the pig-bed, not only from his knowledge of the charge which has been used, and the working conditions of the furnace, but also from the appearance of the iron when running into the moulds, and from the surface of the pigs. Hard white iron is more sluggish, but brighter, and produces more sparks when flowing from the furnace, and it gives a rougher surface to the pig than soft grey iron, which, on the contrary, flows with a characteristic "break" and a smooth or velvety appearance. When the pigs are sufficiently cooled they are removed from the pig-beds, broken, and classified according to fracture. There are several systems of classification in use, that prevailing in South Staffordshire being as follows:—

No. 1. Which has a very open grain, and is a soft grey foundry iron.

No. 2. An open grain soft grey foundry iron, not quite so coarsely crystallized as No. 1.

No. 3. A soft grey foundry iron, but somewhat closer in the grain than No. 2.

[1] Full particulars and illustrations of such machines will be found in *Cassier's Magazine*, vol. 24, p. 113.

No. 4. This is as a rule the most important grade, and on this account it is divided into two, or sometimes into three varieties :—

(*a*) No. 4. Foundry,—which is the greyest and the softest.

(*b*) No. 4. An intermediate variety.

(*c*) No. 4. Forge,—which is stronger and very close grained, though still all grey.

No. 5. Mottled iron.

No. 6. White iron.

All mine iron, which is a characteristic and deservedly popular product of the Staffordshire district, is usually classified into eight grades, viz. :—

Nos. 1, 2, 3, and 4. Ordinary foundry qualities, in descending order of softness and fluidity.

Nos. 5. and 6. Closer grained and more suitable for the forge, or for chilled castings.

No. 7. Mottled iron.

No. 8. White.

There is no uniform method of grading adopted through the whole of the United States, but the systems usually followed do not differ greatly from the above, although in America more attention is devoted to the grading of irons which are rich in silicon, as they are used by founders for softening purposes, and in many cases with more discrimination than in the old country. In the Southern parts of the United States the method of grading adopted in 1889 was as follows :—

1. No. 1. Foundry	4. No. 1. Soft	7. Grey Forge
2. No. 2. Foundry	5. No. 2. Soft	8. Mottled
3. No. 3. Foundry	6. Silver Grey	9. White

Of these grades Nos. 1, 2, 3, 7, 8 and 9 resemble irons of a similar class in the United Kingdom. The other irons are silicious in character, and are specially graded.

Connection between Grading and Chemical Composition.

It will be seen from what has been before stated, that the fractured surface of the iron which has been run into the pig-bed presents marked differences in appearance, varying from the very open grained soft grey at the one extremity of the series to a perfectly

white and hard iron at the other. The intermediate varieties include various close grained irons and also mottled pig, which, as its name implies, is a mixture of white and grey. In "grey mottled" the chief part of the fracture is grey, with white parts here and there; in a "white mottled," on the other hand, the chief part of the fracture is white, but dark grey patches occur at intervals.

It will be interesting now to see how, in a typical case, these various grades of iron differ in chemical composition. The following table gives the analyses of a series of Cleveland pig irons examined by C. H. Ridsdale:—

	No. 1.	No. 2.	No. 3.	Forge.	Mottled.	White.
Carbon, graphitic, .	3·20	3·16	3·16	2·72	1·84	
,, combined, .	trace	·20	·48	·58	1·25	3·05
Silicon, . . .	3·50	2·90	2·59	1·93	1·01	·67
Sulphur, . . .	·05	·06	·08	·10	·32	·40
Phosphorus, . .	1·67	1·69	1·57	1·55	1·57	1·60
Manganese, . .	·68	·62	·60	·75	·62	·42

From these figures it will be seen that the elements with which we have to deal include carbon, which is returned in two forms, graphitic and combined; silicon, sulphur, phosphorus, and manganese. It will further be noted that the phosphorus is fairly constant throughout the series; and also that there is no regular variation in the proportion of manganese. On the other hand, it will be observed that the four other constituents vary in the series under consideration in a manner which shows remarkable regularity. The graphitic carbon is at its maximum in No. 1 iron, and gradually decreases until it suddenly disappears when we pass from mottled to white. Conversely, the combined carbon, of which there is only a trace in No. 1 iron, steadily increases until, in white iron, the whole of the carbon is in this condition.

It may be well here to so far anticipate as to explain that the sudden cooling of grey cast iron tends to produce a white metal, while, on the other hand, slow cooling of white iron tends to the production of a grey metal. But in the case under consideration all the samples were cast and cooled in a similar manner, so that some other explanation must be sought in order to account for the difference in the condition of the carbon and the physical properties of the iron. This cause is found when the proportion of silicon and

of sulphur is examined, the silicon being at its maximum in the softest iron and steadily decreasing through the series; while the proportion of sulphur is lowest in the No. 1 pig, and increases regularly as we pass through the series to the white iron. These typical changes may be more conveniently studied when the analyses are represented diagramatically, as in fig. 14.

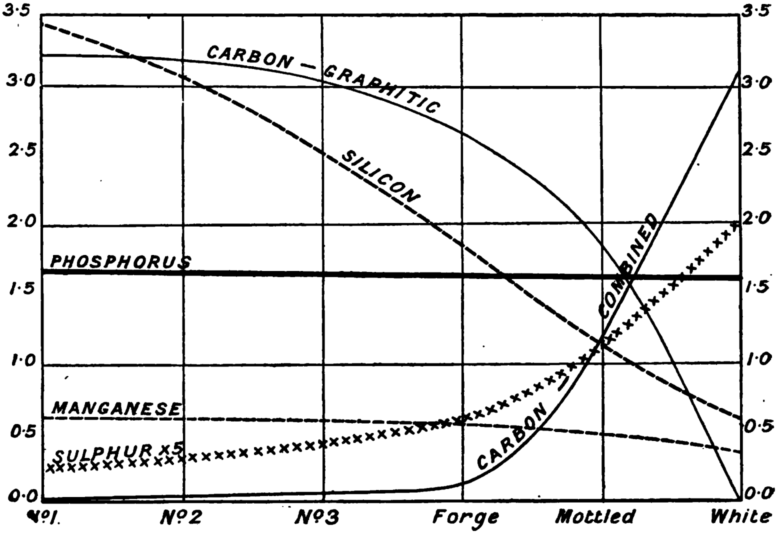


FIG. 14.—Diagram illustrating the grading of Cleveland Pig Iron.
Percentages.—Sulphur is multiplied by 5 to render it more visible.

The Density of Cast Iron.

It may be interesting here to note that the density of cast iron varies with the grade, being highest in white iron, and lowest in very graphitic or silicious iron. The following table, based on figures given by W. J. Keep (*Cast Iron*, p. 28), will illustrate this change.

	Density.	Weight per cub. foot.
Pure Iron	7·84	489 lbs.
White Cast Iron	7·60	474 ,,
Mottled Iron	7·53	458 ,,
Light Grey Cast Iron . . .	7·20	450 ,,
Dark Grey Cast Iron . . .	6·80	425 ,,

It will thus be seen that, with castings that are reasonably free from blow holes, the grade can be approximately determined from the density of the metal, if this is known.

Unreliability of Fracture as a Test of Quality.

It might perhaps be supposed from the analyses of a regular series of samples such as those above given that it would be possible by examining the fracture of a sample of pig iron to determine its chemical composition and physical properties. It is true that in many foundries where a "rule of thumb" method is followed it is still customary to determine the suitability of pig iron for a particular purpose by the appearance of the fracture. There is no doubt that men of long experience, working with known irons, can in this way obtain uniform results in a manner which is surprising to those who have had less practical experience of the subject. But should there be any change in the source of supply of the iron, or any variation in the rate of cooling in the pig, the foundry manager is apt to find himself entirely at fault if he depends merely upon fracture; nor can even an experienced chemist determine, from the appearance of samples which are submitted to him, exactly, or, in many cases, even approximately, what the composition is likely to be. It must be remembered that there are so many variables in connection with the chemical composition of pig iron, some of which produce one effect, and others almost exactly the opposite, that however useful a guide fracture may be in some cases, it is entirely misleading in the remainder. The intelligent and successful iron-founder of the present day, while carefully examining the fracture of all the iron he uses, also adopts physical tests to control the quality of his mixture, and checks these from time to time by chemical analyses. It is only by such a combination of science and practice that satisfactory results can be continuously obtained. But before the iron-founder can make his mixtures with intelligence it is necessary for him to understand the influence of the various elements which are constantly present in the pig iron which he uses, and this information will, as far as possible, be given in the next lecture.

LECTURE III.

CONSTITUENTS OF CAST IRON. CARBON IN CAST IRON. FORMS OF OCCURRENCE OF CARBON. COMBINED CARBON. SEPARATION OF GRAPHITE. SILICON IN CAST IRON. SILICON IN THE FOUNDRY. SULPHUR, PHOSPHORUS, MANGANESE, ALUMINIUM, ARSENIC, COPPER, AND TITANIUM IN CAST IRON. COMPOSITION OF STRONG CAST IRON, AND OF TYPICAL AMERICAN IRONS.

LECTURE III.

Constituents of Cast Iron.

Cast iron is not an element, nor is it a compound, nor an alloy. It is a complex aggregation which includes elements and compounds, and supplies examples both of chemical combination and of mechanical admixture. In the previous lecture it was shown that the substances which are usually present in cast iron include carbon, silicon, sulphur, phosphorus, and manganese. In addition to these, other elements are met with in greater or less proportion. Titanium, for example, is not an uncommon constituent, especially when the iron has been produced from Scandinavian ores. Arsenic, too, is usually present in small quantities; in other cases, copper, chromium, and tungsten can also be detected. With sufficient care traces of many other elements can be recognised by the analyst, but these are of no importance to the practical iron-founder. In old analyses it was not uncommon to find calcium or aluminium returned as being present in cast iron, but it may now be regarded as proved that these elements are not met with in ordinary practice, though they do occur in alloys of iron produced in the electric furnace. The elements which are regularly present in cast iron may be divided into three classes, acccording as to whether they are essential, fairly constant, or variable in amount. In the first class carbon stands alone. It is an essential constituent of all cast iron, since with less than some 2 per cent. of carbon the characteristic properties of cast iron are not obtained.

In the second class of elements are included those which are fairly constant in all grades of pig iron made from a particular ore mixture. These elements are phosphorus and manganese, and also the less common constituents, arsenic, copper and titanium. It has

already been seen that the proportion of manganese and of phosphorus is very similar in all grades of iron made from Cleveland ironstone, and the same is true with irons made from, say, Cumberland hematite, or Lake Superior magnetite, or any other ore of tolerably uniform composition. It may be mentioned, however, incidentally, that sometimes the proportion of manganese is less in a white iron than in a grey iron from the same ore mixture. This is probably due to the effect of the sulphur in the pig, but the difference is not so great as to materially affect the product from the point of view of the iron-founder.

The elements of the third class are those which vary with the temperature and rate of working of the blast furnace; with small variations in the composition of the charge; and other similar circumstances, and which therefore may vary from day to day, or even from hour to hour. These elements are silicon and sulphur, and to them the iron-founder must pay special attention if a uniform product is desired.

It will now be convenient to consider in detail the influence and state of combination of each of the elements which are ordinarily present in cast iron.

Carbon in Cast Iron.

When pure iron is heated with pure carbon, the iron readily takes up more or less of the carbon, the amount which is absorbed depending upon circumstances of temperature and time. If the iron is not pure a third condition is introduced, namely, the proportions of other elements which may be present. The effect of time and temperature in the absorption of carbon is well illustrated in the ordinary cementation process for the production of steel. In this process bars of iron are heated in contact with carbon for periods which vary according to the quality of steel which it is desired to produce. The time taken is usually about seven days, but this may be longer or shorter if specially high or low carbon steel is desired. By heating iron with excess of carbon in a crucible to a somewhat higher temperature than is employed in the steel converting furnace, it is easy to introduce, in two hours or less, some 2·5 per cent. of carbon, which is more than is taken up during cementation in a week. But by raising the iron to an even higher temperature, while still keeping it in contact with solid carbon, the proportion of carbon

which is absorbed may, without difficulty, be made to reach, or even to exceed, 4 per cent. of the weight of the product.

The maximum proportion of carbon which can be dissolved by iron is about 4·25 per cent., the results of some experiments by E. H. Saniter[1] being as follows:—

At cementation heat	(about 900° C.) ...	2·95 per cent.
By fusion	(at about 1400° C.) ...	4·00 „

When experimenting in an inverse direction, namely, by fusing a specially prepared carbide of iron (Fe_3C), instead of by adding carbon to iron, the same observer found that the carbide, on fusion, parted with its excess of carbon until it reached 4·27 per cent., which appears to be the saturation point of pure iron with pure carbon at the melting point. This saturated solution of carbon in iron is stated to be the iron carbon eutectic, and to melt at 1130° C.

The percentage of carbon which can be dissolved by iron is, however, markedly affected by the presence of other elements. Manganese and chromium lead to an increased solubility of carbon in iron at high temperatures, and to the production of what is called "combined carbon" when the metal cools. Silicon and aluminium, on the other hand, diminish the power of the iron to take up carbon, and by throwing carbon out of solution as the metal cools, produce graphitic or grey cast iron.

Forms of Occurrence of Carbon.

It is a matter of common knowledge, to which reference has already been made, that certain kinds of grey cast iron if cooled quickly become hard and brittle, while some varieties of white cast iron, if allowed to cool slowly, or when long annealed, become grey and soft. This characteristic change is connected with the fact that carbon exists in cast iron in more than one form. Usually two distinct forms are recognised, which are known respectively as "graphitic" and "combined," but, as will be explained later, each of these varieties may be again divided into two kinds which possess distinctive properties.

It is easy to demonstrate that in grey iron carbon exists in a graphitic form, separate from the iron. Perhaps the simplest form of experiment is to take a pinch of turnings of grey cast iron in the fingers, and rub them on the palm of the hand, when it will be found

[1] *Jour. Iron and Steel Inst.*, 1897, ii. p. 128.

that the skin receives a shiny graphitic polish. No such effect is obtained if turnings of wrought iron, or of steel, or crushed white iron, be treated in a similar manner. Graphite can also be more or less perfectly separated from grey cast iron by sifting the turnings through muslin, by magnetic separation, by washing with water, or even by carefully blowing with air. The graphite when so obtained is seen to be in the form of thin flat plates, which burn when heated to redness in air or oxygen. The graphite can also be plainly seen when a polished prepared specimen of grey cast iron is examined under the microscope. (See figs. 49 and 50.)

A convenient method of observing the properties of graphitic carbon is afforded by the removal of the iron by means of an acid, when the graphitic matter is left behind and can be readily examined. The iron may be employed in the form of small pieces, say the size of a nut, and covered with hydrochloric acid which has been previously diluted with about half its volume of water. The action is allowed to proceed slowly in the cold, and the spent acid is poured off from time to time and replaced by fresh. After a few days a residue will be obtained from which practically all the iron has been removed. This may now be washed with water, treated alternately with a solution of caustic potash, to dissolve the silica and combined carbon, if any, and with acid to remove the last traces of iron. Finally, it should be extracted with hydrofluoric acid, washed with water, and dried. It will now be observed that if ordinary open grained grey iron, such as No. 1 pig, has been employed, the graphite is in bright glistening flakes which are not unfrequently of great beauty. But if the metal used were malleable cast iron (*i.e.*, white iron rendered grey by prolonged heating to about 800°C.), or an ordinary close grained grey casting, or what is known as "glazed" pig, which is a special variety of silicious iron, in each of these cases a graphitic residue of a different character would be obtained. These graphitic residues would still blacken the hands, and possess the peculiar lubricating quality which we associate with blacklead. The carbon burns in air, but is in the form of a very fine powder of a dark grey or of a black colour, quite distinct from the brilliant flakes obtained from an open grained soft iron. The two varieties might then in common language be distinguished as being respectively flaky and powdery. The flaky variety may be regarded as true graphite. The dark grey powder is graphite in a state of very fine division, while the black powder is amorphous carbon. For

this amorphous variety of carbon the eminent German metallurgist Ledebur has suggested the name of "temper carbon." This name is derived from the German term for annealing, and must not be confused with the ordinary English word "temper" as applied to steel.

Careful examination of white iron will also show that the combined carbon does not all occur in one form. It is observed, for example, in the analyses of steel that the results obtained by the ordinary Eggertz carbon colour tests are much lower when the metal has been previously heated to a high temperature and rapidly cooled, than with steel in its unhardened or natural condition, the colour developed by carbon in hardened steel being only about one-half of that produced by ordinary carbide of iron. Again, if grey cast iron be dissolved in hydrochloric acid under ordinary conditions, the whole of the combined carbon passes away with the hydrogen which is evolved; but Ledebur has shown that it is possible, by using dilute acid in the cold, to separate the combined carbon into two parts, one of which is capable of resisting the effect of cold acid. To this variety the name of "cement" carbon has been applied. The amount of the more easily evolved combined carbon is estimated by subtracting, from the total carbon present, the carbon found in the residue as above prepared by treatment with dilute acid. Hence the name of "missing" carbon has been applied to this portion of the combined carbon. It is interesting also to note, in connection with the above, that white cast iron, in which the carbon exists wholly in the combined form, when examined under the microscope, is found to consist of two distinct portions, namely, a white base of uniform texture, called cementite, on which is seen a dark pattern, fern-like in character, and pearlitic in structure. (See fig. 48.)

It will thus be noted that while the chemist only distinguishes two kinds of carbon—combined and graphitic—it is necessary, in order to understand the properties of cast iron, to recognise four varieties, namely:—

1. Coarse grained carbon or graphite.
2. Fine grained carbon, called amorphous carbon or temper graphite.
3. Combined carbon.
4. "Missing" carbon, which usually occurs in relatively small quantities in cast iron.

As the amounts of these four constituents are not separately estimated by ordinary chemical methods, it is impossible from a

chemical analysis alone to determine the physical properties of a sample of cast iron; hence the importance of combined physical and chemical tests.

The proportion of total carbon present in ordinary foundry iron is usually about 3 to 3·5 per cent. Generally speaking, irons which are in other respects pure and good, are high in total carbon, while, conversely, commoner pigs often have their total carbon relatively low. Low total carbon, however, is not necessarily a disadvantage, as it is observed that metal with low carbon, but otherwise relatively pure, produces closer grained castings than when too much carbon is present. It is well known to practical men that a strong casting can be obtained by melting iron or steel scrap with soft grey pig, and in this case the total carbon is naturally lower than usual. The special strength so obtained is probably due to the fact that, owing to the iron being unsaturated, the carbon is not separated in large flakes, which would produce a soft weak iron, but is precipitated in the temper form which is essential to the production of castings of the greatest strength. (See fig. 52.)

Combined Carbon in Foundry Practice.—It has already been mentioned that the condition in which the carbon occurs in cast iron is dependent upon circumstances which include rate of cooling, proportion of carbon, and amount of other constituents. It is frequently stated that slow cooling converts white iron into grey while rapid cooling causes grey iron to become white; but the practical founder knows that such a statement is only true in certain cases, as soft grey iron can be obtained which will run into sheets scarcely thicker than writing paper, or will fill up the vent holes in the mould in long needles, no thicker than ordinary knitting needles, and yet which will retain its grey fracture. On the other hand, white cast iron is produced which, even when very slowly cooled, or if long annealed, still retains its carbon in the combined condition.

Though a moderate alteration in the proportion of total carbon, or of graphite, in a sample of cast iron, will frequently have but little effect on the physical properties of the product, a small change in the proportion of combined carbon will often very materially alter the strength of the casting, and its suitability for the purpose in view. Probably no other constituent in cast iron is so important in its effects as combined carbon, and in fact the influence of the other elements is largely due to the effect which they are able to produce

by increasing or diminishing the proportion of carbon which is retained in the combined form. The following percentage of combined carbon will be found approximately correct for the purposes specified :—

		Combined Carbon.
Extra soft silicious grey iron	. . .	0·08
Soft cast iron	. . . . .	0·15
Cast iron of maximum tensile strength	. .	0·47
,, ,, ,, transverse strength	. .	0·47
,, ,, ,, crushing ,,	over	1·00

These figures are for castings about 1 inch in square section, and will vary according to the size of the castings and other circumstances. It may be remembered, as a general rule, that the hardness of the metal increases regularly with the increase of combined carbon.

Professor Howe has suggested that the maximum strength is obtained in cast iron when the combined carbon is between 1·0 and 1·2 per cent., and the graphite as low as possible. An iron of this kind is however apt to be too hard to be readily machined, and so would not meet with general favour from engineers, in this country at all events.

Chilling irons are usually relatively low in silicon, containing from about 0·5 to 1·5 per cent. of that element; they are grey, close grained in structure, and tough and strong in character.

The proportion of silicon which is required to be present in an iron in order to cause the precipitation of carbon as graphite varies considerably according to the quantity of total carbon present, and, more particularly, with the proportion of sulphur, manganese and other elements which are present at the same time. Swedish cast iron containing as little as 0·25 per cent. of silicon is sometimes quite grey, while Staffordshire all-mine cold blast iron may be grey with only about 0·5 per cent. silicon. On the other hand, samples of less pure iron are sometimes met with containing from 1·5 to 2 per cent. of silicon, in which the carbon is still almost entirely in the combined condition.

Separation of Graphite.—The researches of the last few years have thrown much light upon the changes which lead to the separation of carbon during the solidification and subsequent cooling of molten cast iron. It was formerly supposed that the whole of the graphite was separated during the act of solidification. This view

was supported by the observation that kish, which is a form of graphite in large flakes or plates, separates from grey cast iron when the metal is kept long fluid, as in the hearth of the blast furnace, or in a foundry ladle. But the researches of W. J. Keep, to which further reference will be made (see Chap. V.), have shown that important changes take place in the red hot metal after it has become solid and while it is still cooling in the mould. It will be sufficient here to observe that with ordinary grey cast iron there are three distinct arrests in the rate of contraction or expansion observed while it is cooling from the molten state to the temperature of the air. Similarly with grey cast iron there are also three arrests noted in the cooling curves taken by a recording pyrometer, through the same range of temperature. Though there is room for much further observation in this interesting direction,[1] sufficient work has already been done to show that there is a considerable separation of graphitic carbon from grey cast iron long after the metal has become solid, and some most important changes take place at or below 900° C. These cooling arrests present some analogy to the effects observed when certain varieties of steel are cooled through the same range of temperature.

In cast iron these changes of volume appear to be connected with the separation of temper carbon, and when well marked are characteristic of strong, soft foundry metal.

The iron-founder may perhaps at first be a little overwhelmed with the apparent complexity which is introduced by further knowledge in reference to the states in which carbon occurs in cast iron, and the conditions under which it separates, but doubtless many of the difficulties which were formerly met with in reconciling the results of chemical analyses with the physical properties of the castings were due to empirical methods; and with improved knowledge, doubtless, such difficulties will gradually disappear.

Silicon in Cast Iron.

All cast iron contains more or less silicon, the usual proportions being from about 0·25 per cent. in specially pure, or in white pig iron, to a maximum about 4·5 per cent. in ordinary blast furnace practice; but pig iron which contains 10 per cent. of silicon is regularly made in the blast furnace for special purposes, and 15 per cent. or 18 per cent. of silicon can be introduced in the blast furnace if required.

[1] See Note, p. 131.

By the use of the electric furnace any proportion of silicon which is desired may be obtained; 30 per cent. and 50 per cent. ferro-silicons are now commercial articles, while the element itself can be purchased, of about 98 per cent. purity, for less than 10s. per lb. The rich alloys are, however, like the element itself, too expensive and too infusible to be profitably employed by the iron-founder.

In reference to the mode in which silicon occurs in cast iron, it was at one time believed that silicon was present both in the combined and in the graphitic form. But more careful investigations conducted in recent years[1] have shown that silicon always exists in cast iron as a silicide. This silicide, according to Carnot and Goutal,[2] usually has a composition corresponding to Fe_2Si, though from rich ferro-silicons the compound FeSi has been isolated, while, when much manganese is present, a silicide $(FeMn)_3Si$ may also occur.

When irons which contain a considerable porportion of silicon are microscopically examined, the silicide is observed in characteristic crystalline forms; but in ordinary foundry iron, in which the silicon does not exceed 5 per cent., the silicide cannot be distinguished by the eye, as it exists in the form of a solidified solution in the iron, and forms part of the structureless matrix from which the graphite is at first thrown out, and from which the phosphorus eutectic, if present, afterwards separates.

It was at one time very generally held that silicon was injurious in all proportions when present in cast iron, though it had been pointed out by Sefström, by Snelus, and still more plainly by Ledebur, that with irons in which much silicon is present the carbon is wholly, or nearly wholly, in the graphitic state. It was also known that certain silicious irons obtained in the United States could be advantageously used as softeners in the foundry; but it may be claimed that there was no accurate or quantitative knowledge of the influence of silicon previous to 1885, when my first paper on "The Influence of Silicon on the Properties of Cast Iron" was published in the Journal of the Chemical Society. The principle adopted in connection with these experiments was extremely simple, though it does not appear to have been previously applied. The practice had hitherto been to endeavour to deduce from the analyses of samples produced in actual practice the influence of the various elements which were present. On account of the number of variables which have to be considered,

[1] For an outline of these researches see *Metallurgy of Iron*, p. 197.

[2] *Inst. Jour.*, 1899, vol. i. p. 453. See also P. Lebeau, *ibid.*, 1901, vol. ii. p. 513.

this, which may be called the analytical method, involves a very large number of observations being made before any definite conclusion can be drawn. For the other, or what may be called the synthetical method of investigation, cast iron was first specially prepared so as to contain as little silicon and other impurities as possible. It was then mixed with ferro-silicon, containing about 10 per cent. silicon, so as to give a graduated series of test bars with definite proportions of silicon, while the other elements were kept as nearly as possible constant. By adopting this method more information was obtained from a single series of experiments than could have been gained by many years of practical observation, and the synthetical method of investigation in the hands of Arnold, Hadfield, Keep and other investigators, has since widely extended our knowledge of the metallurgy of iron and steel. As applied to cast iron, the synthetical method, by elucidating the influence of silicon, gave the key to the successful application of scientific knowledge in the iron-foundry. Subsequent experiments following similar lines, and particularly those conducted by Mr W. J. Keep, have determined with great accuracy and completeness the influence of the other elements which are present in foundry iron.

Returning now to the influence of silicon on cast iron, I have a series of samples of the turnings obtained from the test pieces produced in the original experiments, the results of which were, as before mentioned, published in 1885. These samples are arranged in order of silicon content. Those who have had any experience in the working of cast iron will see at once a marked difference in the properties of the various members of the series. Commencing at the one end with pure cast iron, the metal was so hard as to be cut only with the greatest difficulty, and the fragments chipped off in small irregular pieces. At the other end of the series the 10% silicon pig was so brittle that it could be crushed to powder in a steel mortar, though it was too hard to be readily cut in the lathe. The intermediate members of the series exhibited gradations in softness and working qualities, the samples from about 2 to 3·5% being particularly soft, and their turnings are in the shape of those twisted spirals which are so characteristic of metal which can be readily machined.

The series therefore illustrates the fact, which cannot be too often insisted upon, that cast iron with either too little or too much silicon is relatively hard and brittle; and that the proportion of

silicon must be varied according to the particular purpose which is in view.

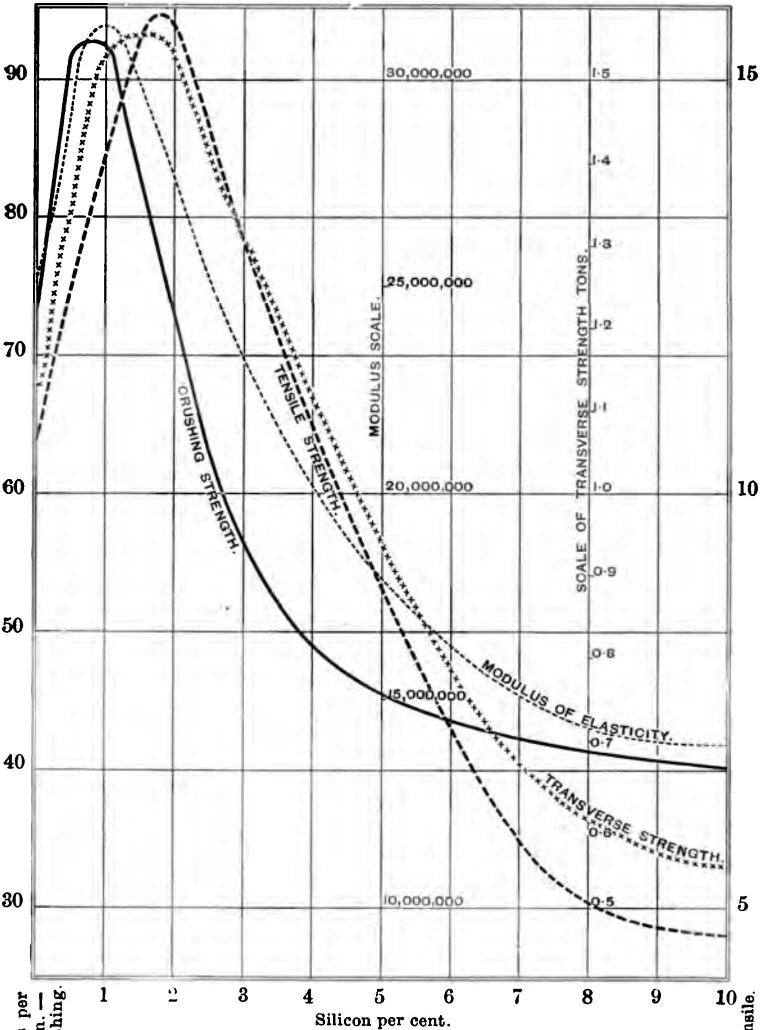


FIG. 15.—Influence of Silicon on the Properties of Cast Iron.

The pieces from which these turnings were obtained were carefully

tested for tensile and crushing strength by Professor Kennedy. They were also analysed, the analyses being checked by Mr J. P. Walton, and the results of these tests are embodied in the table given on page 60. These results may be conveniently expressed graphically as in fig. 15,[1] from which it will be seen that for crushing, transverse, and tensile strength respectively, the influence exerted by silicon is of a uniform character, which may be represented by a curve rising to a maximum. But it will be observed that the maximum point is different in each case, thus emphasising the necessity for a composition in accordance with the special properties which are desired in the product. In these experiments the proportions of silicon corresponding to the various properties were as follows:—

Maximum hardness, ...	under 0·80	per cent.
Crushing strength, ...	about 0·80	,, ,,
Modulus of elasticity, ...	,, 1·00	,, ,,
Density in mass, ...	,, 1·00	,, ,,
Combined crushing and tensile strength :		
transverse strength, ...	,, 1·40	,, ,,
Tensile strength, ...	,, 1·80	,, ,,
Softness and working qualities, .	,, 2·50	,, ,,

But it must be borne in mind that these values are only true under the circumstances of these particular experiments, and the most suitable amount of silicon varies according to the proportion of sulphur, manganese and other constituents, and also with the size of the casting. It has, however, been amply demonstrated in actual practice that the figures as above given are approximately correct. The hardness in this series of samples was determined by the means of a "sclerometer" (see fig. 39), the results being expressed by the weight in grams, pressing upon a diamond point, required to produce a standard scratch on the polished surface of the metal. The result is graphically shown in fig. 16, from which it will be noted that the maximum hardness was obtained with white iron; that the hardness steadily decreased with the addition of silicon until 2·5 per cent. was reached, when with further addition of silicon the hardness was again increased.

The influence of silicon on cast iron was reinvestigated by Mr W. J. Keep of Detroit, and the results of his investigation have since

[1] *Metallurgy of Iron*, p. 194.

been published in a convenient form in a volume entitled *Cast Iron—A Record of Original Research,* which should be read by every one interested in the scientific aspect of iron-founding.

Mr Keep has pointed out that white iron frequently does not give sound castings, and that blowholes lead to lower specific gravity and diminished strength; but a small addition of silicon eliminates blowholes and produces sound castings. As soon as the metal is sound the greatest crushing strength is obtained. This condition gives the maximum density; further addition of silicon leads to the formation of graphite and diminished brittleness, and gives the greatest transverse and tensile strength. When the graphite is further increased, the metal is divided by the interspersed graphitic

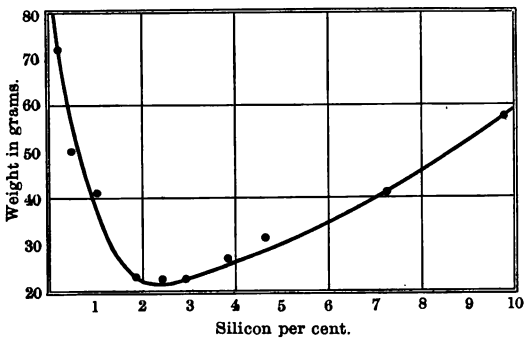


FIG. 16.—Silicon in Cast Iron, Hardness Tests.

material, which is now in a coarser state of aggregation, and the strength and hardness of the casting are decreased. The deflection also increases with the increase of graphite, but when the maximum separation of graphite has taken place, any further addition of silicon causes stiffness or brittleness.

Mr Keep also drew attention to the important fact that white iron shrinks more during solidification than grey iron, and hence on adding silicon to white iron the shrinkage is diminished. The amount of shrinkage closely follows the proportion of combined carbon in cast iron—so closely, indeed, that it is found in practice that the hardness of the metal may be judged with considerable accuracy by a shrinkage test. Hence a shrinkage test acts as a control on the proportion of graphite, and indirectly also on the percentage of silicon. When discussing the influence of silicon on

EFFECT OF SILICON ON THE PROPERTIES OF CAST IRON.

Silicon per cent. (calculated).	Relative Density at 20° C. (Water at 20° C.=1.)		Relative hardness.	Tensile Strength=per Square Inch.		Modulus of Elasticity.	Crushing Strength per Square Inch.		Calculated Transverse Strength. Bars 1 foot long, 1 inch square, loaded in the centre.		Chemical Analysis.						
	Cylinders.	Turnings.		Lbs.	Tons.		Lbs.	Tons.	Lbs.	Tons.	Total Carbon.	Graphite.	Combined Carbon.	Silicon.	Phosphorus.	Manganese.	Sulphur.
0	7·560	7·719	72	22,720	10·14	25,790,000	168,700	75·30	2,702	1·206	1·98	0·38	1·60	0·19	0·32	0·14	0·05
0·5	7·510*	7·670	52	27,580	12·31	28,670,000	204,800	91·42	3,280	1·464	2·00	0·10	1·90	0·45	0·33	0·21	0·05
1	7·641	7·630	42	28,490	12·72	31,180,000	207,300	92·54	3,370	1·504	2·09	0·24	1·85	0·96	0·33	0·26	0·04
1·4	7·555	7·473	...	31,440	14·04	23,500,000	183,900	82·08	3,498	1·561	2·21	0·50	1·71	1·37	0·30	...	0·05
2	7·518	7·350	22	35,180	15·70	23,560,000	137,300	61·29	3,446	1·538	2·18	1·62	0·56	1·96	0·28	0·60	0·03
2·5	7·422	7 388	22	32,760	14·62	25,450,000	172,900†	77·18†	3,534†	1·577†	1·87	1·19	0·68	2·51	0·26	0·75	0·05
3	7·258	7·279	22	27,390	12·23	21,150,000	128,700	57·45	2,850	1·272	2·23	1·43	0·80	2·96	0·34	0·70	0·04
4	7·183	7·218	27	25,280	11·28	15,640,000	106,900	47·74	2,543	1·135	2·01	1·81	0·20	3·92	0·33	0·84	0·03
5	7·167	7·170	32	22,750	10·16	18,720,000	103,400	46·16	2,342	1·046	2·03	1·66	0·37	4·74	0·30	0·95	0·05
7·5	7·128	7·138	42	11,950	5·34	14,750,000	111,000	49·55	1,505	0·672	1·86	1·48	0·38	7·33	0·29	1·36	0·03
10	6·978	6·924	57	10,630	4·75	13,930,000	76,380	34·10	1,252	0·559	1·81	1·12	0·69	9·80	0·21	1·95	0·04

* This number is rather low, as the specimen afterwards proved to be somewhat faulty.

† The value in this case is probably exceptionally high; a crushing strength of about 60 tons might be anticipated from its position in the series.

cast iron, it is customary in some quarters to speak as though the only effect exerted by silicon is that due to the separation of graphitic carbon. Professor Howe, for example, regards cast iron as a mixture of graphite and a metallic matrix, and its strength as dependent on the relative absence of the former, and the approximation of the latter to steel, and has elaborated this view at considerable length, and with characteristic care and ability. (*I. & S. Inst. Jour.*, 1903, i. p. 706). But it is important to recognise two other effects produced by silicon in addition to its power of separating graphitic carbon. In the first place, both the tensile strength and hardness of carbon free iron are increased by the addition of silicon, which acts in this respect much like combined carbon in iron or steel, but in a less energetic manner.[1] Excess of silicon, however, like excess of carbon, causes the metal to become crystalline, so that rich ferro-silicons are sufficiently brittle to break easily when struck with a hammer, and can be readily crushed to powder. Secondly, it is noted that the size of the graphite is influenced by the judicious addition of silicon, since what may be termed freshly precipitated graphite, obtained by adding silicon to a hard iron, is smaller in size than that which exists in an ordinary soft foundry iron, and consequently the metal is closer in texture and stronger when, by the addition of silicon, a portion of the graphite has been thrown out of solution in this form. We are therefore justified in claiming a specific influence for silicon itself in addition to that which it exerts upon the state of combination of the carbon present. In order to accurately understand the constitution of cast iron, it is necessary to consider not only the total amount of graphite, and the proportion it bears to the combined carbon, but also the texture of the graphite and the effect of other elements on the matrix in which the graphite is found. It will be seen, when discussing the influence of the other elements upon cast iron, that each has a specific and beneficial influence when present in suitable proportions, though the amount which can be introduced with advantage is very much less with certain elements than with others.

Silicon in the Foundry.—From what has already been said, it will be evident that, with pig irons of what may be regarded as good or normal composition, the regulation of the proportion of silicon is the

[1] Additional proof of this statement will be found in the results published since these lectures were delivered. (See T. Baker, "Silicon in Iron and Steel"—*I. & S. Inst. Jour.*, 1903, vol. ii.

key to successful foundry practice. The question then arises as to the most economical and convenient method of obtaining in practice the required proportion of silicon. In special cases it has been found advantageous to use ferro-silicon containing 10 per cent. of silicon and upwards, and this method was adopted with advantage, particularly in France, in 1886. Ferro-silicons, however, possess two disadvantages; in the first place, they are relatively expensive, and are sold at prices varying with the silicon content. Further, they differ considerably both in fusibility and density from the iron with which they are to be mixed, and as a result the product is apt to be irregular in composition. When using a mixture of irons which differ considerably in an analysis, there is also the irregularity caused by relatively small errors in the order, or the time, of charging the metal into the cupola. On the whole, therefore, it is found more economical to use a mixture of such irons as are commonly met with in practice, and this method of mixing has the advantage of ensuring greater uniformity both in the supply and in the product. The ideal method is for the founder to have a fairly large stock, including several kinds of iron, each separate kind being a little too hard, or a little too soft, for the general run of work, but still not very different from what is required. By mixing these irons in suitable proportions, it is then easy to obtain any composition which may be desired, it being, of course, assumed that the composition of each variety is already known.

Sulphur.

The proportion of sulphur which is met with in foundry irons is usually small, and while the carbon and silicon are expressed in percentages, the sulphur is returned by the analyst in 100ths, or at most 10ths of one per cent. It may be noted as a curious fact that American irons are generally much freer from sulphur than are many varieties produced in the United Kingdom. Despite the small proportion of sulphur which is usually present in foundry irons, its influence is so energetic that it deserves special attention, since relatively small variations may entirely change the character of the product. Briefly stated, the effect of sulphur is to counteract that of silicon; it leads to the production of combined carbon, and consequently to increased shrinkage and hardness. On the other hand, metal which is unusually free from sulphur is apt to be somewhat too soft, and a little wanting in strength and rigidity. It is not

possible to give any figures which would be of general application, but the iron-founder would usually be safe in considering that one part of sulphur will neutralise the useful effect of at least 10 parts of silicon. For soft fluid castings the sulphur should be as low as possible, or say about ·03 to ·04 per cent. For strong metal about ·07 per cent. gives good results; but it is doubtful if it is advantageous under any circumstances to introduce more than about 0·10 per cent. sulphur into foundry mixtures. The sulphur which is present in cast iron exists as sulphide of iron, which is readily fusible, and is probably the last constituent to solidify as the metal cools. As a result, the sulphur is apt to be very unequally distributed in a mass of iron, sometimes being found chiefly in the upper and outer part of the pig, as when much manganese is present; but in other cases the sulphur collects chiefly in the centre of the casting. Considerable care is therefore necessary, in order to obtain a fair average result, when sampling pig iron for the purpose of analysis.

Phosphorus.

It has already been mentioned that the whole of the phosphorus which is present in the ore charged into the blast furnace is reduced and passes into the pig iron, and that, consequently, the content of phosphorus from a given ore mixture is approximately constant. (See page 13.)

Phosphorus exists in cast iron in the form of phosphide, which is readily fusible, and which in its pure state is brittle and comparatively hard. It has been shown by Stead[1] that more than one phosphide exists in iron and steel, though the one usually met with has a composition corresponding with the formula Fe_3P. This is dissolved by the iron until the proportion of phosphorus reaches about 1·70 per cent., after which the phosphide separates in the free state. Carbon tends to throw the phosphorus out of solution, though this action is not complete even with 3·5 per cent. of carbon. It will be seen that a grey phosphoric iron, when viewed under the microscope, consists of three parts: (*a*) the uniform ground or base consisting of iron, silicon, and manganese; (*b*) graphite; (*c*) the phosphorus eutectic. (See fig. 50.)

A small quantity of phosphorus when present in pig iron is found

[1] *I. & S. Inst. Jour.*, 1900, vol. ii. p. 60.

to be advantageous for many purposes, as it gives greater fluidity, and at the same time increases the strength of the metal. But with larger porportions of phosphorus the phosphide remains fluid while the rest of the metal solidifies, and being deposited throughout the mass, it causes the casting to be brittle, and to fracture easily from shock. So characteristic is this effect of phosphorus that in practice it is found possible to tell approximately the proportion which is present in a sample of pig iron by the readiness with which a pig of a given grade will fracture when thrown upon the pig breaker. The ready fusibility of the phosphide eutectic causes phosphoric iron to be unsuitable for application where the metal has to resist high temperatures, as in the case of ingot moulds, fire-bars, etc., for which purposes hematite iron should be employed. For ordinary strong castings of good quality about 0·5 per cent. of phosphorus gives excellent results, while for the general run of foundry practice, where fluidity and soundness are of more importance than strength, from 1 to 1·5 per cent. phosphorus may be allowed; but beyond this higher limit the further addition of phosphorus causes such marked brittleness as to allow of the metal being used only for very inferior purposes. The presence of phosphorus appears to have little or no effect on the proportion of combined carbon, but it reduces the shrinkage, its action in this respect being direct, and not chiefly through its action on carbon, as is the case with silicon.[1]

Manganese.

Iron can be purchased commercially containing any proportion from 0·1 to about 90 per cent. of manganese. The richer alloys are known as ferro-manganese. Intermediate irons containing from about 5 to 20 per cent. of manganese are called spiegels. With metal so rich in manganese the iron-founder is seldom concerned, though for special purposes the addition of a small quantity of ferro-manganese, as a softener, is occasionally recommended, particularly with sulphurous irons. The presence of manganese tends to increase the proportion of combined carbon, and hence increases the hardness and shrinkage, but decreases the fluidity of the metal. Mr Keep calculated that an addition of 1 per cent. of manganese leads to an increase of 40 per cent. in the hardness of the metal. Strong irons usually contain a certain proportion of

[1] See Keep, *Cast Iron*, p. 79.

manganese, but it is doubtful if it is ever beneficial to introduce more than 1 per cent. in ordinary foundry practice.

We have now considered those elements which are invariably present in greater or less proportion in cast iron. Before leaving the subject, a few words may not be out of place in reference to a few other elements which occur less frequently.

Aluminum.—It was anticipated at one time that an extensive application of aluminum would be met with in the iron-foundry, as the influence of this metal is very similar to that which is exerted by silicon, except that aluminum is more energetic in the conversion of combined carbon into graphite.[1] The use of aluminum for foundry purposes was very carefully studied by Mr Keep, who concluded that for ordinary foundry use silicon was, on the whole, to be preferred. The disadvantages in the use of aluminum are that the cost is increased, while metal which contains aluminum is less fluid than ordinary cast iron, and appears to have a skin upon its surface which prevents it filling the crevices of the moulds. This skin is also apt to break away in the form of scum, which forms irregular patches on the surface of the casting. The amount of aluminum required is so small that the presence of rather more oxygen than usual in the metal may result in little or no aluminum remaining in the casting, and hence the product is apt to be very irregular. At the same time it must be acknowledged that when just the right proportion of aluminum can be introduced the product is often exceptionally good.

Arsenic is frequently present in small quantities in cast iron. Its action resembles that of phosphorus, but the quantity is usually not sufficient to cause the iron-founder any anxiety.

Copper is not an uncommon constituent, but the amounts which are usually present cause no trouble to the iron-founder. In small proportions it is usually rather beneficial than otherwise. The same can be said of nickel in quantities not exceeding about one per cent.

[1] See Melland and Waldron, "The Influence of Aluminium on the Carbon in Cast Iron," *Jour. I. and S. Inst.*, 1900, vol. ii. p. 244.

Titanium is not an unusual constituent of cast iron, though the amount present is seldom over 1 per cent. It imparts a characteristic velvety mottled appearance to the fractured surface of grey cast iron, which is seen in fig. 17. This sample contained 0·28 per cent. of titanium. In the proportions in which titanium is usually present it does not appear to injuriously affect the physical or mechanical properties of cast iron, or to alter the proportion of graphite, or the power to chill. On the other hand, Bahlson states that a small

FIG. 17.—Titaniferous Pig Iron.

quantity of titanium, when present in cast iron, leads to increased bending and tensile strength.[1]

Composition of Strong Cast Iron.

Having thus briefly discussed the influence of each of the elements with which the iron-founder has to deal, it may be well now to consider what may be regarded as a typical cast iron for general foundry purposes. Here it should be mentioned that no particular kind or grade of cast iron is equally good for every purpose. There

[1] *Iron and Steel Inst. Jour.*, 1902, ii. p. 550.

is in fact no "good" or "bad" cast iron, as metal which is entirely unsuitable for one purpose may be exactly what is required for another. As a typical example of good cast iron we may take the material which is employed by the engineer for best qualities of work, where strength, solidity, fluidity, and good working qualities are required. Such a metal, with relatively small alterations of its silicon and other constituents, can be made to answer for any other purpose in the foundry. Examination of a large number of results of chemical and mechanical tests, including those of the American Commission on Metal for Cannon in 1856; the Cast Iron Experiments conducted at Woolwich in 1858; of my own experiments; and of a number of tests recorded by other observers,[1] show that with cast iron the maximum tensile strength is obtained with about 94 per cent. of metallic iron, and with the other elements in approximately the following proportions :—

Graphitic Carbon . . .	2·5
Combined Carbon . . .	0·5
Silicon	1·5
Phosphorus	·55
Manganese . . .	1·00
Sulphur	·075

Starting with this typical composition, the founder can vary his mixture according to the work which may be in hand, having in view the requisite strength, fluidity, price, or other special conditions which may be necessary. In cases where the metal is required to chill, the proportion of silicon usually varies from about ·6 to 1 per cent., the amount depending upon the depth of chill needed and the size of the casting; a lower silicon being naturally employed with larger mases of metal. If a fluid or thin iron is wanted the silicon may be increased to about 3 or 3·5 per cent. and the phosphorus to 1·5. For such material a lower manganese is usually to be recommended, and the metal should be cast at a rather higher temperature than usual. For the production of castings with very fine surfaces, fluid metal with high graphitic carbon and relatively high in silicon and phosphorus is employed, and it is important that the metal should be poured at the right temperature. Smooth finely dressed patterns, which are often of polished metal, are used, and the moulds should be made with sand of good uniform quality, and should

[1] For particulars, see *Metallurgy of Iron*, p. 238.

be well vented. In some cases considerable stress is laid upon the character of the "facing" applied to the surface of the mould, though excellent results are obtained in other foundries in which no special facing is applied.

Composition of American Foundry Iron.

As there is often a distinct difference in the composition of American and British cast iron of the same grade, owing to the former being somewhat lower in sulphur and silicon, it may be well here to include a series of typical specifications for the chemical composition of American foundry irons, as given in the recently issued and valuable Report of the British Iron Trade Commission of 1902 (page 236).

Special Hard Iron (Close Grained).

Silicon must be between 1·2 and 1·6 per cent. (below 1·2 the metal will be too hard to machine; above 1·6 it is liable to be porous unless much scrap be used).

Sulphur must not exceed 0·095 per cent., and any casting showing on analysis 0·115 or more of sulphur will be the cause for rejectment of the entire mix. (Above 0·115 per cent., sulphur produces high shrinkage, shortness and "brittle hard" iron. Exceptionally, however, as for frictional wear in brake shoes, etc., the sulphur may run up to 0·15 per cent.)

Phosphorus should be kept below 0·7 per cent., unless specified for special thin castings. (High phosphorus gives brittle castings under impact.)

Manganese should not be above 0·7 per cent., except in special chilled work.

Medium Iron.

Silicon to be between 1·4 and 2 per cent. (Silicon at 1·5 gives the best wearing result for gears.)

Sulphur must not exceed 0·085 per cent., and any casting showing on analysis 0·095 per cent. or more of sulphur will be the cause for rejectment of the entire mix. (Sulphur preferred at 0·075 to 0·08 per cent.)

Phosphorus should be kept below 0·7 per cent., except in special work.

Manganese should be below 0·7 unless otherwise specified.

Soft Iron.

Silicon must not be less than 2·2 nor more than 2·8 per cent., with a preference for about 2·4. (Below 2·2 per cent., small castings will be very hard; above 2·8 large castings will be somewhat weak and have an open grain.)

Sulphur in no case must exceed 0·085 per cent. High sulphur makes iron "brittle short" and causes excessive shrinkage.

Phosphorus should be kept below 0·7 per cent., except in cases where great fluidity is required, as in thin stove plate, when it may run up to 1·25 per cent. Phosphorus makes iron brittle under impact.

Manganese should be kept below 0·7 per cent., except in chilled work. For a heavy chill the manganese may vary from 0·7 to 1·25 per cent.

Having thus briefly considered the general character and composition of the metal employed by the iron-founder, I propose in the next lecture to deal with the arrangement of the iron-foundry, with the work conducted therein, and with some of the most important problems with which the founder is beset.

LECTURE IV.

THE FOUNDRY. GENERAL ARRANGEMENT. METHODS OF REMELTING CAST IRON. THE CUPOLA. VARIETIES OF CUPOLAS. FUEL USED IN REMELTING. CHEMICAL AND PHYSICAL CHANGES DUE TO REMELTING. MOULDS AND MOULDING. HAND AND MACHINE MOULDS. FOUNDRY LADLES. POURING AND POURING TEMPERATURE. COMMON TROUBLES OF THE IRON-FOUNDER. INFLUENCE OF SHAPE AND SIZE ON THE STRENGTH OF CASTINGS.

LECTURE IV.

The Foundry.

IN many cases the iron-foundry is a part of a larger undertaking, and has grown up as the necessity has arisen for the production of castings to supply the needs of the establishment. As a consequence the space occupied is small, the moulding shop is dark, badly ventilated, and in many cases not provided with any heating apparatus for use during the winter months. Mechanical appliances, too, are conspicuous by their absence, and there is apt to be a general want of attention and care, which under such circumstances cannot fail to react upon the workmen, and upon the character of the work produced.

The ideal foundry is a large well-lighted building, rectangular in plan, erected on a level site, close to railway and water communication, and with plenty of room around the building for sidings, stores, light, air, or future extensions. The buildings should be constructed so as to be well ventilated in summer, and warmed in the depth of winter.[1] The working floor is of earth, but sufficient tram-lines should be provided to allow of ready transport of heavy material. One or more large over-head traversing cranes should be provided, and also a number of smaller jib cranes, so as to allow of the ready handling of heavy moulds and castings. Lastly, due attention should be paid to the sanitary arrangements for the convenience of the men, and these should include facilities for washing, and for some change of clothes, so that the moulders when they leave work may be able to do so with self-respect, and be in a fit state to travel in a public conveyance.

[1] See paper by W. H. Carrier, "On Heating and Ventilation of Foundries and Machine Shops." Amer. Foundrymen's Association, June 1903.

As an example of a modern foundry in the United Kingdom, may be taken that of the British Westinghouse Co., Manchester. This foundry is represented in plan in the folding plate, fig. 18, and in cross section in fig. 19. The main building is about 600 ft. long by 170 ft. wide, and is lofty and well ventilated. There are in addition separate stores, pattern shops, and covered pig yards as indicated in the drawings.

It will now be convenient to enter such a foundry with the pig iron, and to follow it through the various processes which result in the production of a finished casting. It has already been mentioned that in some cases castings are produced from metal taken direct from the blast furnace, but the use of fluid metal in this way is naturally of very limited application and is not to be recommended for best work. In the great majority of cases the iron is first cast in moulds at the furnaces, and the founder receives his metal in the form of pigs, which have been run in sand. For this sand an allowance by weight is made at the furnace. The iron is generally stacked in a pig yard, which usually contains at least three or four varieties of pig iron. It is advantageous when possible to have the pig yard under cover. The founder, by having fairly large stocks of selected iron on hand, is able to obtain a much more uniform product than would be possible with the use of direct metal or of a single brand. The ideal foundry mixture is, as already mentioned, one which consists of several varieties of irons which do not vary too much in chemical composition, hardness or density, and which will, on remelting, readily mix so as to yield a thoroughly uniform product.

Remelting Cast Iron.

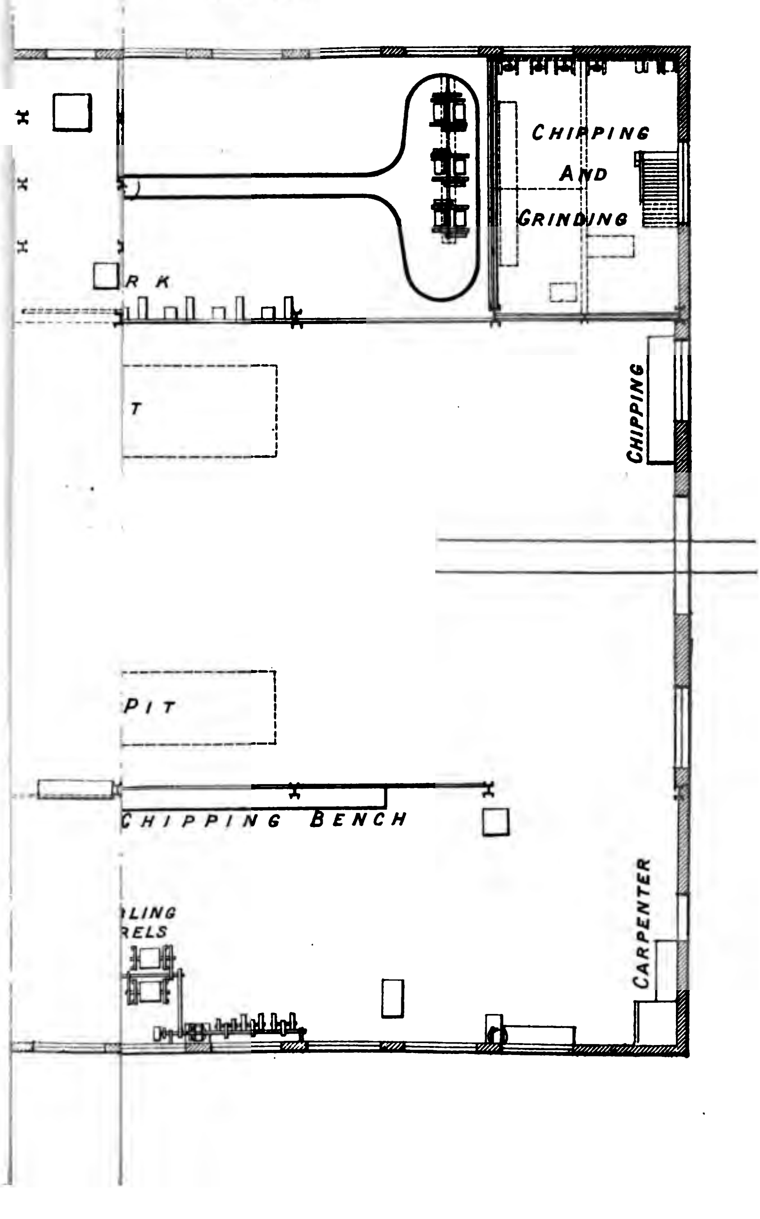
There are four chief methods which are in regular use for the remelting of cast iron in the foundry.

1. **Clay Crucibles** are heated in a wind furnace fired by coke. The charge in each crucible usually does not exceed about 70 lb., and for experimental purposes is often much less. This method of melting is the most expensive in fuel and labour, and is only adopted on a small scale for the production of malleable castings, or for other special purposes.

2. The **Air Furnace** is frequently used where metal of special uniformity is required, as for example in the production of chilled ... The furnace employed for this purpose is of a simple rever-

PLAN OF MODERN FOUNDRY

(Fig. 18, to face page 74.)



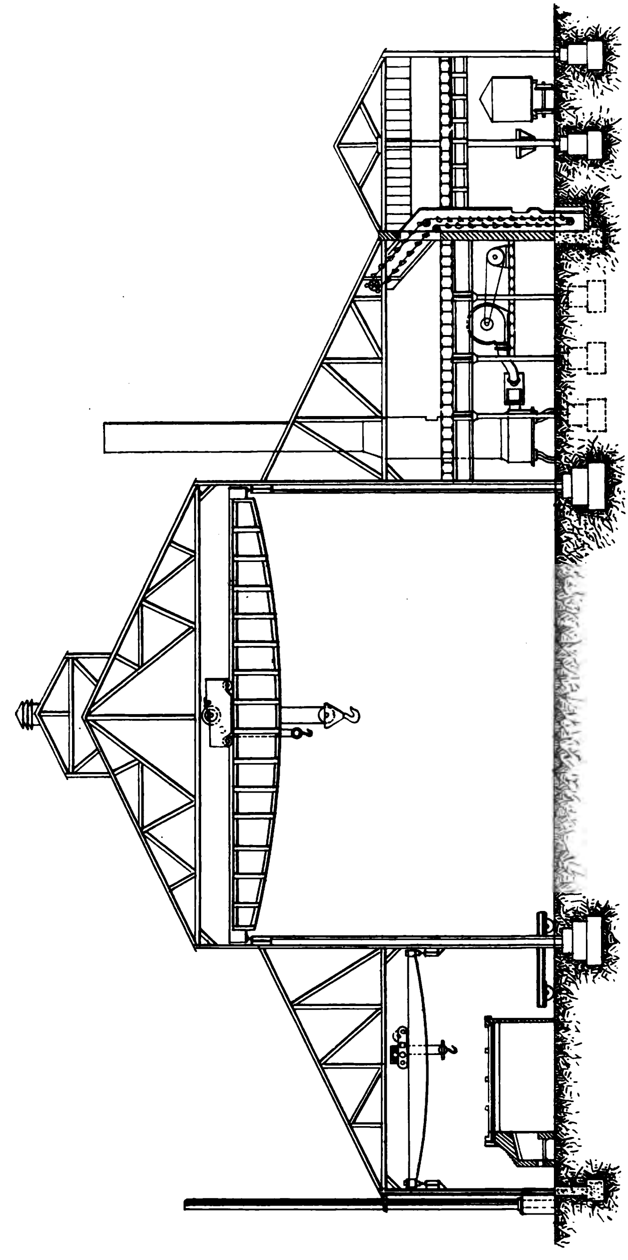


FIG. 19.—Iron Foundry, British Westinghouse Co. Cross Section.

beratory type, the chief point in the construction being that the roof is arched downward, so as to reduce the space in the melting part and cause the flame to play over the surface of the metal. The fuel used is coal, and the furnace has a sand bottom. This method of melting has the advantage of supplying a large bath of metal of uniform composition, and also allows the composition to be varied, if desired, just before the metal is poured. A section of such a furnace is given in fig. 20, and this may be regarded as a typical example of the air furnaces employed in South Staffordshire.

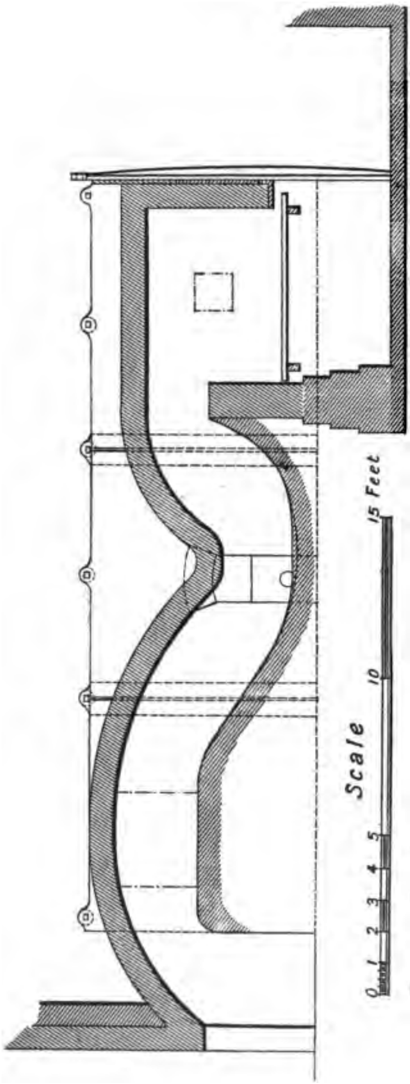


FIG. 20.—Reverberatory or "Air" Furnace for Remelting Pig Iron. Longitudinal Vertical Section.

3. **The Siemens Regenerative Furnace** is now being used in a number of foundries, particularly in America, for the production of malleable cast iron. For this purpose the acid lined furnace with a sand bottom is employed, and grey cast iron is melted with sufficient scrap to give a suitable composition for use in the annealing oven. These furnaces are relatively economical in fuel and labour, and allow of the production of a metal of definite composition, but for general work they cannot compete in economy with the cupola.

4. **The Cupola**, or small blast furnace, is the form of apparatus which is in use in the vast majority of foundries throughout the world, and which is, on the whole, the cheapest and the most convenient arrangement for remelting cast iron for foundry purposes.

Cupolas are generally circular in section; they are lined with ganister, fire-brick or other non-conducting refractory material; and are driven with low pressure blast at or about the atmospheric temperature. Hard coke is generally used for fuel, though occasionally charcoal or gaseous fuel is employed. A small quantity of limestone is usually added, as it fluxes off the sand adhering to the pigs, or the silica produced by oxidation of the silicon in the iron. It also combines with the ash of the coke, and tends to diminish the amount of sulphur which enters into the iron. The blast is driven either by a fan, or more generally by a Roots or other positive blower, the pressure being measured in ounces per square inch. The blast is generally introduced through twyers situated round the zone of fusion.

Varieties of Cupolas.

Cupolas vary from an old boiler tube, lined with a ramming of sand, and fitted with but one twyer (an arrangement which answers sufficiently well for small temporary purposes), to larger and more complex structures capable of melting up to 500 tons per day. Much ingenuity has been expended in the construction of various modified forms of cupolas, the object generally being the reduction of fuel consumption, and the production of a more uniform iron.

The different kinds of cupolas in actual use, or which have been proposed from time to time, are legion. In 1887 M. A. Gouvy, in a paper on cupolas, described no less than thirty-three different kinds, most of which were German. This list did not include the majority of types used in the United Kingdom.

Cupolas may be conveniently classified according to internal shape and arrangement of the hearth; the method of introduction of the air supply; and the kind of fuel employed. Taking these characters in order and dealing first with the internal shape, cupolas may be divided into three kinds.

(1) The old *solid bottomed* type, which is represented in fig. 21, and which is in pretty general use in small foundries in the United Kingdom. It has the advantage of being cheap and easy to work, but is only to be recommended for small

outputs. The charging door, charging platform, tapping hole, blast main, blast pipes, and twyers are sufficiently indicated on the diagram.

(2) *Drop bottom cupolas* are generally employed with large outputs in the United Kingdom and are in special favour in America. The advantage of this system is, that when melting is finished the bottom can be readily removed and the cupola cleaned and repaired. A cupola of this type is shown in fig. 22.

(3) Cupolas with a *receiver*, of which the Stewart's "Rapid" is a well

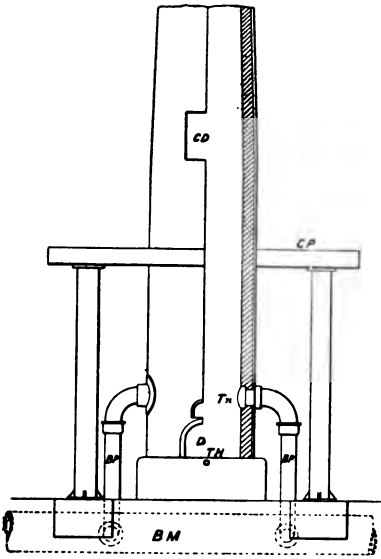


FIG. 21.—Solid Bottomed Cupola.

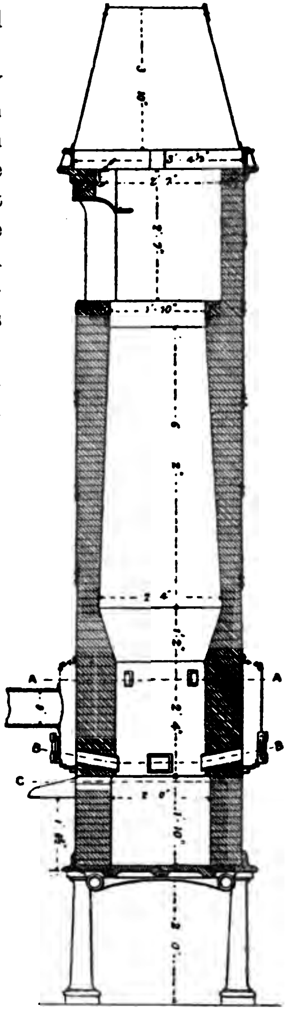


FIG. 22.—Drop Bottom Cupola.

known type, are in use in many foundries in the United Kingdom. Such a cupola is illustrated in fig. 23. These

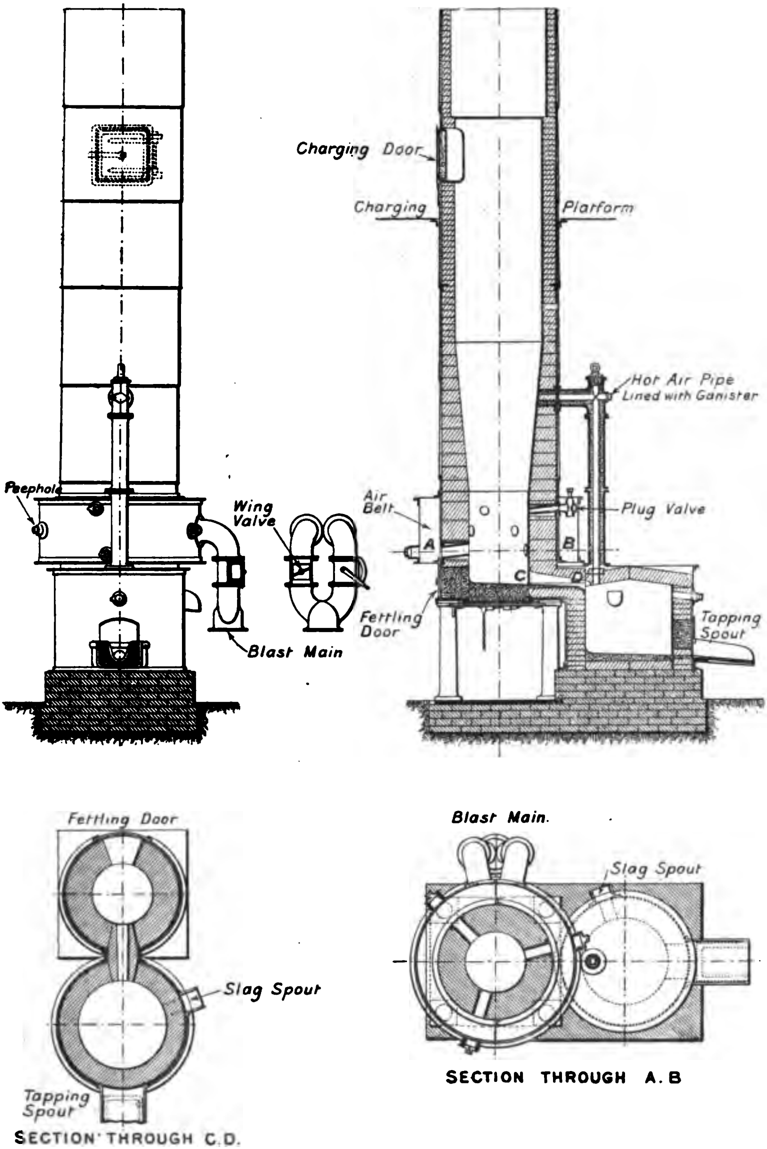


FIG. 23.—The "Rapid" Cupola, with separate Receiver in Elevation and Sections.

furnaces are driven with a forced draught in the ordinary way, and the special point is that they are provided with a separate receiver in which metal can be allowed to accumulate so as to obtain an iron of special uniformity in such quantity as may be required. In cupolas which are not provided with a separate receiver the amount of metal which can be accumulated at one time is determined by the vertical space between the bottom of the hearth and the point at which the air enters. By a suitable size and shape of hearth many of the advantages of a cupola with a receiver can be obtained without having a separate outside vessel.

When regarded from the point of view of the method whereby the air is supplied, cupolas may also be divided into three kinds.

(1) *Cupolas with one row of twyers.*—In ordinary practice the air enters under pressure, through openings placed in a horizontal plane around the sides just above the hearth. Various attempts have been made to heat the air, or to inject fuel with the air, but these have not been successful. The reason no doubt is, that the combustion which takes place in a cupola is essentially different in character from that occurring in a modern blast furnace, where, it will be remembered, the air is almost instantaneously converted into carbon monoxide on entering the hearth. In the cupola, on the other hand, carbon dioxide is first produced, and this is converted into monoxide higher up in the cupola on coming in contact with heated coke. As the carbon monoxide is not wanted for any reducing action, any excess burns to waste at the throat of the cupola.

(2) *Cupolas with more than one row of twyers.*—In Ireland's cupola, which was introduced about 1860,[1] two rows of twyers were employed, and the cupola was provided with boshes like a blast furnace. Such a form is found to give very satisfactory results with large outputs, the introduction of air higher up in the cupola being advantageous, as it leads to the more complete combustion of the carbon monoxide produced as above explained. The Greiner and Erpf cupola is of this type, and has met with much favour in Germany; it is provided with a circle of five or six twyers around the melting zone, while about 12 or 18 small twyers, each about

[1] For illustrated description, see F. Kohn, *Iron and Steel Manufacture*, p. 53.

one inch in diameter, are placed around the furnace higher up in a spiral form.

(3) *Suction Cupolas.*—In other cases the air for combustion, instead of being forced in under pressure, is aspirated by means of a steam jet arranged in a tube or chimney connected with the cupola. The Woodward cupola which was introduced in 1860[1] is of this type; and more recently the Herbertz cupola, which is of the same class, has met with considerable favour in Germany. In cupolas of this construction the air is admitted through a circular slit or ring around the melting zone of the cupola.

Fuel Used in Remelting.

It is unnecessary to deal in detail with the classification of cupolas according to the kind of fuel they employ, since, as already stated, coke is almost universally adopted, though exceptionally charcoal, gaseous fuel, or even oil may be employed.

The coke most generally used is oven coke of good quality, what is known as 72-hour coke being preferred in the United States. It should be bright and hard, low in sulphur, and should contain as little ash as possible. Retort oven coke, *i.e.* coke made in bye-product ovens, gives good results in the cupola, if it is free from excess of ash and sulphur. The question of strength is not so important in cupola practice as in blast furnace work. The consumption of fuel varies according to the efficiency of the cupola, the care of the melter, and more particularly with the quantity of iron which is melted per day. With good average work in the United Kingdom about 2½ cwts. of coke are required per ton of pig iron. This may be increased to more than twice as much with small outputs, while with especial care and large yields as low a fuel consumption as 1¼ cwts. per ton of pig iron is sometimes recorded. In the United States it is usual to return the fuel consumption or "melting ratio" in lbs. of iron melted per 1 lb. of coke, and in practice it is found that 1 lb. of coke should carry from 8 to 16 lbs. of pig iron. In some foundries considerable preventable waste of fuel occurs. One instance was brought under my notice some years ago where the coke consumption was over 12 cwts. per ton of pig iron melted. The gentleman who owned the foundry was attending

[1] For illustrated description, see F. Kohn, *Iron and Steel Manufacture*, p. 53.

a course of lectures similar to those now being delivered, and at first doubted the correctness of my figures as to coke consumption; but by merely directing proper attention to this point, and without introducing any special appliances, he was able to save more than one half of the coke, and yet obtain perfectly satisfactory results. In making comparisons it is important to state whether the blank charge used in heating up the cupola is calculated, and also if the test has been conducted over a sufficiently long period to allow of uniform results being obtained.

Chemical and Physical Changes due to Remelting.

It is well known to practical founders that grey cast iron, when remelted, either in the cupola or in the air furnace, becomes harder with each melting, until ultimately it is quite unsuitable for ordinary foundry purposes. So long ago as 1853, Sir William Fairbairn performed a series of experiments in order to ascertain the exact effect of remelting. He took a soft grey iron containing upwards of 4 per cent. of silicon, and remelted it in an air furnace 18 times, a sample bar being taken from each remelting. I am fortunately able to show a quantity of drillings taken from representative bars prepared in this series of experiments, the samples having been preserved at the time by Professor Unwin. It will be seen that the turnings exhibit the general character of the silicon series, being very hard at the one end, somewhat hard at the other, and quite soft in the middle of the series. The conclusion at which Sir William Fairbairn arrived was that iron improved up to the twelfth melting, after which it rapidly deteriorated.

On analysing the samples in 1886, I was able to ascertain the cause of the changes which took place. The result of the analyses is given in the following table:—

Compositon of Test Bars from Sir W. Fairbairn's Experiments.

No. of Melting.	Total Carbon.	Combined Carbon.	Silicon.	Sulphur.	Manganese.	Phosphorus.
1 . .	2·67	0·25	4·22	0·03	1·75	0·47
8 . .	2·97	0·08	3·21	0·05	0·58	0·53
12 . .	2·94	0·85	2·52	0·11	0·33	0·55
15 . .	2·98	1·31	2·18	0·13	0·23	0·56
14 . .	2·87	1·75	1·95	0·16	0·17	0·58
16 . .	2·88	...	1·88	0·20	0·12	0·61
18 . .	...	2·20				

These results can be graphically represented as in fig. 24. As the proportion of sulphur is relatively small, and its effect most important, the percentages of this element are, in the diagram, multiplied by 20.

It will be seen from these results that during the remeltings the silicon steadily decreased, while the sulphur and combined carbon increased, the natural effect being that the metal gradually became harder, and when the 12th melting was passed became too hard, and was ultimately weak and brittle.

It is interesting to compare fig. 24 with fig. 14, since it will be seen that there is a marked similarity in the direction of the changes. In

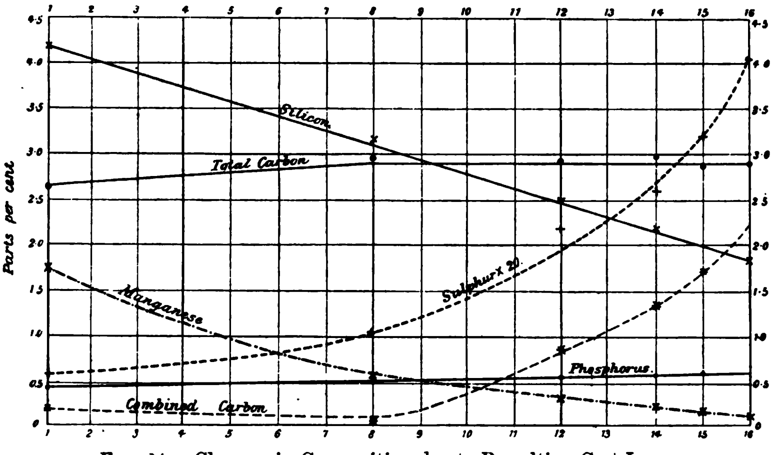


FIG. 24.—Changes in Composition due to Remelting Cast Iron.

other words, starting with an open grain iron, and remelting, all grades can be obtained from open grey to quite white.

The general principles observed in these experiments have been amply confirmed by many later investigators, and are of considerable importance, since the nature of the changes which take place in the remelting of cast iron in the air furnace are the same as those which take place in the cupola, the Siemens steel furnace, or the Bessemer converter. It is of course a fallacy to suppose that mere remelting either improves or deteriorates the quality of the cast iron. The effect of remelting will chiefly depend upon whether the iron already contains too much graphitic carbon and silicon. If so, remelting will be advantageous; if not, then remelting will be injurious. The

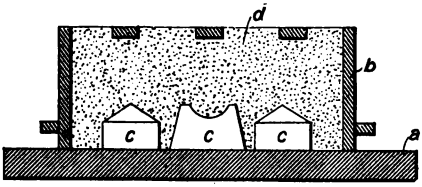
practical founder should remember that when grey cast iron is remelted in the cupola it usually loses about 0·25 per cent. of silicon, and takes up about ·03 per cent. of sulphur, so that in calculating foundry mixtures a suitable allowance must be made for the effect which remelting will produce.

Moulds and Moulding.

While the metal is being thus remelted in one part of the foundry, the moulds into which the fluid iron is to be poured are being prepared by the moulders in an adjoining shop. Moulds may be conveniently divided into four kinds, each of which is used for a special class of casting.

(1) **Green Sand Moulds.**—These are the cheapest and most readily prepared, and are in use for the majority of purposes. They are made in a great variety of shapes and sizes, and of varied intricacy. The term "green" sand does not refer to the colour of the sand, but is used because the moulds are not specially dried or otherwise prepared, the sand being used in its raw or green state. The moulds are made in boxes or "flasks," which are retangular in shape and which in the United Kingdom are made of iron, though in America wooden flasks are commonly employed. The relative advantage of the two kinds has been much discussed. Iron boxes can be made in the foundry; they last longer, and when done with can be remelted; the cost is therefore trifling. Wooden flasks, on the other hand, are lighter, and when worn out can be used for firewood. On the whole, light iron boxes are to be preferred where there is a constant demand for work of the same kind. The sand to be used for the preparation of the moulds should first be sieved to remove shots of iron or lumps, and should then be damped and thoroughly mixed. A suitable casting sand is fine in texture and refractory, and should absorb sufficient water to allow of its becoming firm when rammed or pressed, but must still retain considerable porosity, as upon this property the success of the casting largely depends. The sand should not be too wet, or it will interfere with the free exit of the gases, and either prevent the mould from being properly filled or lead to the production of blowholes. Before the mould can be made, it is of

course necessary to provide a suitable pattern of the article which is required. These patterns are generally made of wood, in a separate shop, by patternmakers.[1] For special work, iron patterns are employed, and occasionally patterns are made of gun metal, of polished German silver, or other metal. In some foundries where there is a considerable variety of work, and some of the patterns may be repeated at only long intervals, there is a tendency for patterns to accumulate and to occupy a great deal of space. This should be avoided as far as possible, as it is better to make a new pattern when necessary than to store a number of old ones which require space and trouble for their preservation, and which, apart from the danger of fire, are often found to be more or less deteriorated when again required for use.



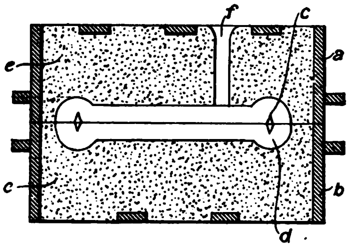
a, board ; *b*, casting box ; *c*, simple patterns ; *d*, sand.
FIG. 25.—Simple form of Patterns and Mould.

Perhaps the simplest example of moulding is with castings such as are represented in fig. 25, where articles are required, one side of each of which is flat and the rest of the pattern contains no re-entering angles. In such a case the patterns are placed face downwards on a board, the flask is then put in position above the patterns as shown, sand is thrown into the box and lightly rammed. When the mould has been thus filled it is "vented" (by means of a tool like a steel knitting needle stuck in a wooden handle) so as to allow of the ready escape of gas. It is then inverted, the board removed, and the patterns gently tapped and taken out. A channel called the "git" or "gate" is provided, so as to allow the metal to enter the mould, and also, if necessary,

[1] The subject of pattern making is very important to the founder, but scarcely comes under the head of metallurgy. J. L. Gobeille has recently given an illustrated account of a Modern Pattern Shop.—*Jour. Amer. Foundrymen's Assocn.*, June 1903.

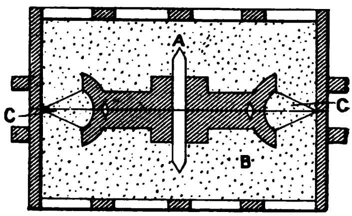
to pass from one part of the mould to another. A flat box filled with sand is clamped in position, to replace the board which originally held the pattern, and the mould is ready for pouring. In moulding it is of course essential that the sand should be rammed sufficiently to give an accurate impression of the pattern, but hard ramming should be carefully avoided, as this not merely involves additional labour but renders the sand too dense and helps to produce blowholes in the castings.

The number of articles having flat sides, as in the above very simple illustration, is of course comparatively small, and usually the pattern is made in two (or more) parts, one of which is provided with pins, and the other with sockets.



a and *b*, casting box, top and bottom halves; *c* and *d*, pattern, top and bottom halves; *e*, casting sand; *f*, gate.

FIG. 26.—Simple Pattern and Flask.



A, core; B, green sand; C, separate part.

FIG. 26A.—Simple Cored Mould.

One half of the pattern in such a case is placed on the board and rammed with sand as before. The box is then inverted, and the other half of the pattern is placed in position; a little fine sand, called parting sand, is then dusted over the surface of the mould so as to prevent any sticking of the sand to the other portion of the mould which has still to be made. The other half of the flask is now placed in position; it is kept in place by pins or wedges, and is rammed as usual. When this is finished (see fig. 26), the upper part of the mould is removed, and should take with it the upper half of the pattern, one half of each pattern remaining in the upper portion of the mould. The patterns are then gently tapped and removed, the two parts of the flask are

placed in position again, and the mould is ready for use. In a great many cases, however, articles are required in which it is impossible, on account of re-entering angles or internal spaces, to make a pattern which could thus be divided into two parts. It is therefore necessary to make the mould in sections, as in the simple case shown in fig. 26A, where it is necessary for the part C to be separate from the main parts of the mould A and B. For parts which lie inside the pattern, but which are not intended to be filled with metal, cores are provided. These are usually made of green sand, and are kept in position by iron pins or other means. For small work, cores are often made by pressing sand in a suitable mould, such work being not unfrequently done by women. For larger purposes, as, for example, with the long cores which are required in the production of cast iron water pipes, cores are made by winding hay bands round a tube, and plastering them over on the outside with wet loam, to which a certain amount of dung is usually added in order to give porosity. The tubes round which the hay bands are wrapped are often made in segments, so as to be collapsible for ready removal after the metal has been poured. Loam cores must be carefully dried before being used, and for this purpose special drying ovens are provided in the foundry. In modern foundries drying ovens are now very commonly heated with gas, and small cores are dried on movable perforated iron trays, which are made to slide in one above another until the whole oven is full. Hot air is also in favour for core drying.

On account of the cost and labour involved in the production of loam cores in pipe founding, many attempts have been made to introduce some other system of preparation. A promising step in this direction is the automatic pipe-core forming machine recently introduced by Mr W. Jones of Stourbridge, which is illustrated in fig. 27. In this machine a green sand core is formed upon an iron tube of suitable size, which is perforated in places so as to allow of the ready escape of gas. To cause the sand to adhere, in the first place the tube is covered with a clay wash, and the core is shaped by allowing the sand to fall upon the surface of the tube, while it is caused to rotate at the rate of about

seven revolutions per minute. A smooth steel edge serves at the same time to rub off any excess of sand, and to give the required shape. By means of an eccentric on the main shaft a reciprocating motion is imparted to this steel edge, which thus makes about 300 strokes per minute. The cores are produced in a clear and rapid manner, and can be at once used without drying; they appear to answer admirably for pipes of moderate size.

(2) **Dry Sand Moulds** are used for special purposes in the foundry, the object generally being the production of a single casting, without the cost of providing a pattern. The sand is first prepared of approximately the shape which is required, and while it is dry and comparatively hard, it can be easily cut or rubbed so as to give the exact form needed, and the

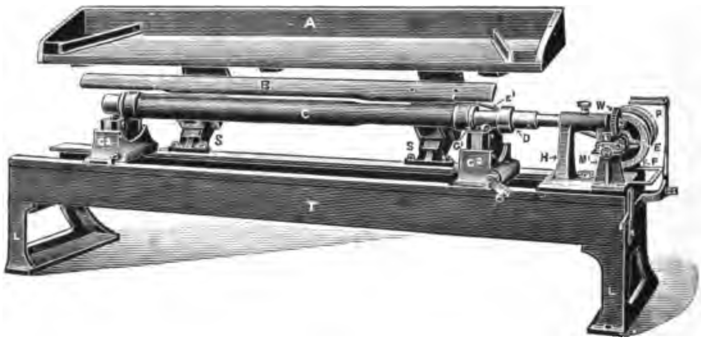


FIG. 27.—W. Jones' Pipe Core Moulding Machine.

A. Adjustable Shelf for carrying Sand.
B. Bar (Steel reciprocating) shaped to suit straight, socket, taper or bell-mouth cores.
C. Core on Core-barrel.
C.[1] Collars same diameter as required core.
C.[2] Carriage with roller bearings, to carry core barrel, adjusted vertically by means of rack and pinion.
D. Driver (or Sliding Collar) for driving core barrel.
E. Eccentric.
E.[1] Eccentric Rod.
F. Fly Wheel on Main Shaft.
G. Gear (striking) for driving belt.
H. Headstock.
L. Legs to carry tablecasting.
M. Main Shaft.
M.[1] Main Shaft Brackets.
P. Pulleys (fast and loose).
R. Rollers to carry reciprocating bar.
R.[1] Brackets for ditto.
S. Saddle, with adjustable Screw motion, carrying roller bracket and sand shelf.
T. Table or Bed.
W. Worm gear, steel worm and wheel, machine cut and hardened.

metal can be poured without any further special preparation of the mould, other than such facing as may be required.

(3) **Loam Moulds** are used when large objects with curved surfaces are produced, the commonest examples being sugar pans, cast-iron boilers, and similar articles. By this method a separate mould must be prepared for each article which is cast. It is built up roughly of brick-work in the first place, iron tie bars being used as required to strengthen the structure, which is then covered with loam, the surface being carefully finished to the desired shape. The mould is afterwards thoroughly dried before use. Loam moulding is relatively troublesome and expensive, and is only employed when the shape required is such as cannot be conveniently produced by other means. A form of permanent mould for such purposes, which only requires the daubing on of loam and blacking for each casting, has been described by J. A. Murphy, and appears to give rapid and satisfactory results.[1]

(4) **Cast Iron Moulds or Chills** are used for many purposes in iron-founding, among the commonest examples of such application being those employed in the bedstead trade. When small castings are produced in chills, the upper portion of the iron mould is very commonly taken off after the iron is solidified, but while it is still red hot, as this prevents the chill being too sharp owing to too rapid cooling through the range of temperature of from about 900° to 700° C., where, as was seen in Lecture III., p. 54, there is an important separation of graphite during slow cooling. In producing chilled rolls, a composite mould is generally employed, the two ends being cast in green sand; and the centre portion of the surface of the rolls, where a hard wearing surface is required, being chilled. The weight of the chill should in all cases bear a suitable proportion to the size of casting to be employed. Chills are not used cold, but at a temperature of about 150° C. If chills are used at atmospheric temperatures a violent explosion may occur on account of the moisture from the air which is condensed upon the surface of the iron. If the chills are too hot, on the other hand, naturally there is the danger of the casting sticking to the mould.

[1] *Jour. Amer. Foundrymen's Association*, June 1903.

Machine Moulding.

In foundries where a large number of "repeat" orders, or orders of one kind, have to be executed, machine moulding is now very commonly applied, and is steadily growing in favour, particularly in America. Moulding machines are only used for the production of green sand castings, and in such machines it is of course necessary to use flasks and patterns as usual, but the machine largely reduces the labour, and increases the uniformity, when work of the same class is being continually turned out. Moulding machines cannot be used for intricate shapes or re-entering angles, but are especially suitable for work of a simple character which allows of the patterns being mounted on a board; or, where the pattern can be divided into two parts and mounted, either on two sides of one board, as in one class of machine, or on two separate boards, as in another form of machine.

Moulding machines answer admirably with patterns which are shallow, or when a number of small patterns can be grouped on one plate, when the mould is easy to ram, and when the rammed part can be easily withdrawn. In some cases patterns have to be withdrawn with a special motion or at an angle. For such work machine moulding is unsuitable, as the machine will only lift vertically. Work having a good deal of detail, provided it is shallow, can be readily done with a moulding machine, as can also cylindrical sections. On the other hand, castings of great depth and intricacy, or those with middle parts, cannot be so successfully done with machines as by hand.

An interesting paper on the moulding machine has been published by S. H. Stupakoff,[1] in which paper the various mechanical methods adopted in such machines are outlined, and a useful classification is given. This may be abridged as follows:—

1. Moulding: (*a*) bench moulding, (*b*) floor moulding.
2. Floor moulding: (*a*) loam, (*b*) dry sand, (*c*) green sand.
3. Green sand moulding, (*a*) hand moulding, (*b*) machine moulding.
4. Machine moulding: (*a*) operated by hand, (*b*) operated by power. Hand moulding machines are then classified according as whether they are stationary or portable; lever, screw, or

[1] *Jour. Amer. Foundrymen's Association*, June 1903.

geared; single action or double action; and according to the various methods employed for pressing, stripping, withdrawing, etc. Power driven moulding machines are also classified into single action, double action, and multiple action; into belt driven, pneumatic, hydraulic, steam, electric and vacuum; and according to the methods of ramming, drawing, pressing; the kind of pattern used, etc.

This classification will give some idea of the large number of machines which are now employed, and the very varied size and design which have been adopted.

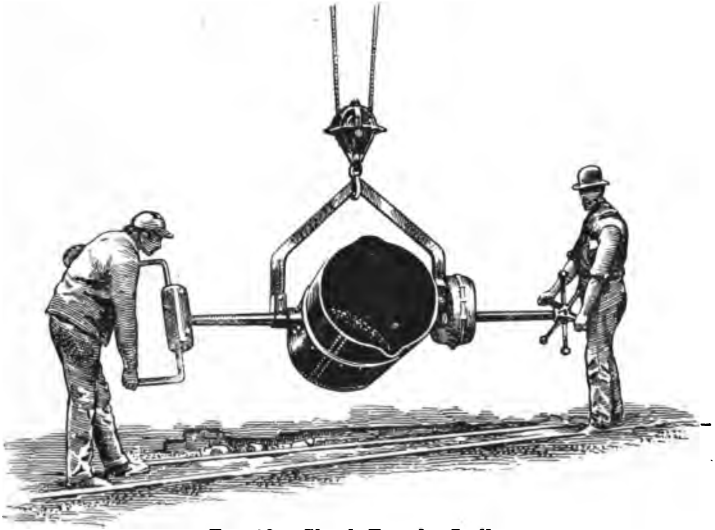


FIG. 28.—Shank Foundry Ladle.

The subject of moulding machines has also been considered in an illustrated paper by E. B. Gilmour,[1] who points out that one great advantage of such appliances is the great economy of space and improved accuracy, as rapping and shaking are not necessary for the withdrawal of the patterns. In order to prevent the outer surface of the mould becoming too hard, owing to squeezing, it is well to place a loose frame, about $1\frac{1}{2}$ in. thick, on the top of the flask, and when the mould is squeezed this frame is removed and the hard surface of sand scraped off the flask.

[1] *Jour. Amer. Foundrymen's Association*, June 1903.

Foundry Ladles.

The mould having been prepared, and the metal melted in the cupola, the iron is tapped out as required into foundry ladles, which are made of wrought iron or mild steel, and lined with fire-clay or other refractory material, which is of course dried and heated before the ladle is used. The size and shape of the ladle will depend upon

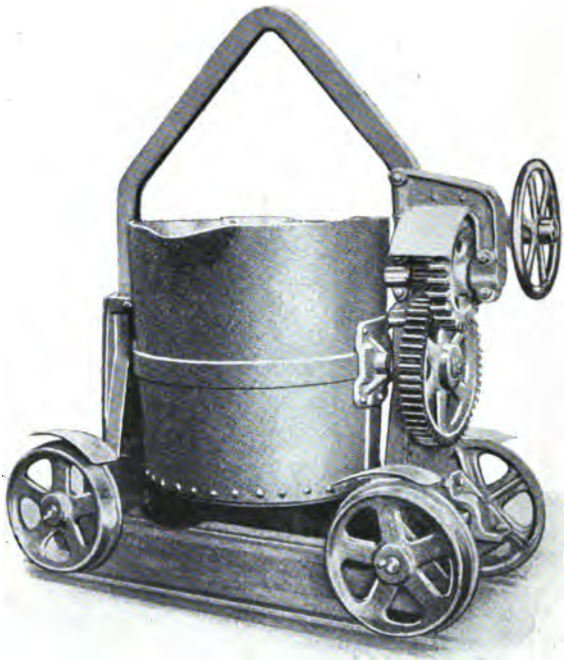


FIG. 29.—Large Foundry Ladle.

the work in hand. For small work, hand ladles are commonly used, but for the majority of purposes a shank carried by two men is employed. For still larger castings the ladle is handled as shown in fig. 28. For heavy castings a foundry ladle capable of holding several tons is necessary, and this is usually provided with wheels and run on a line of rails, as shown in fig. 29. In some cases the

ladle is carried overhead by a large traversing crane, but this is objectionable owing to liability to accident. In the iron-foundry of the British Westinghouse Works, Manchester, the fluid iron is carried on what is known as the Colburn trolley track, which consists of an overhead rail rolled to a suitable section in order to enable two trolley wheels to support the ladle shaft. The ladle is pushed by hand, and this method of transport is stated to be extremely convenient. (See fig. 18.)

Pouring and Pouring Temperature.

Usually the metal is at a temperature above the proper casting heat when it is received into the ladle, and it may be necessary to wait a short time before pouring. It is important in the casting of all metals that the proper temperature of pouring should be selected, otherwise, if too high a temperature has been employed, the product is apt to have a rough surface, to be deficient in strength, and to contain blowholes. On the other hand, with too low a temperature the mould may not be properly filled.

Cast iron is not so sensitive to the effect of variations due to pouring temperatures as some other metals, and herein lies one of its great advantages, in that castings are not so readily spoiled by a little want of care and attention. At the same time it is important that cast iron should be poured at the proper heat, and many of the minor troubles of the iron-founder are due to want of attention in this respect. It is, however, sometimes very difficult to ensure exactly the proper pouring temperature, as a number of moulds have to be filled out of the same ladle, and it is therefore necessary to begin pouring while the metal is a little too hot, while, at the finish, it is probably cooler than it should be in order to produce the best effects.

The proper temperature will, of course, vary according to the size of the casting, the general rule being that the smaller the work, and the more intricate the pattern, the higher must be the temperature, in order to obtain the required fluidity. In many cases it is necessary to provide two or more gates in a flask, as otherwise the iron would not retain its heat sufficiently long to flow into all parts of the mould. It is then important that the pouring should be properly timed, so that the iron should enter each gate at the same moment and so ensure the complete filling of the interstices of the

mould. When the casting is sufficiently cooled, the box is opened and the sand removed. A considerable amount of sand, however, closely adheres to the surface, and with small castings this is usually got rid of by means of a tumbling barrel, which is a revolving iron box, usually hexagonal in cross section, in which the castings are caused to rotate until their surfaces are clean. For larger castings a pneumatic sand blast is used with satisfactory results.

Foundry Costs.

The cost of producing castings will naturally vary very considerably according to locality, output, size, quality, and other considerations, so that it would be quite impossible to lay down any definite rules which would be of universal application. By comparison of returns obtained from a large number of typical foundries in America in 1901 it was ascertained that the average cost of producing 100 lbs. of castings was approximately 137 cents, or 5s. 8½d. This cost did not include rent, taxes, interest, depreciation, or other variable charges, and was made up as follows:

	cents.	*s.*	*d.*
Metal	76·94	3	2½
Melting	4·36		2¼
Moulding	·80		½
Cores	1·61		¾
Salaries	47·29	1	11¾
Miscellaneous	5·83		3
	136·83	5	8¾

From these figures it will be observed that the cost of the metal is more than one half of the total, while the salaries, which presumably include wages, absorb over one-third of the whole expenditure; the remainder of the costs added together do not reach 10 per cent. of the total. In recent years there has been a distinct tendency towards increased foundry costs in American practice.

Common Troubles of the Iron-Founder.

Before leaving this part of the subject it may be well to refer to some of the many troubles which beset the iron-founder and to indicate their usual cause and remedy.

(1) **Shut Ends.**—This is the term employed when the metal, instead of filling the whole of the mould, has only flowed for a certain distance, and then stopped. Such defects are usually the result of want of fluidity in the iron, or, in other words, are due to the fact that too hard a metal has been employed. A small increase in the proportion of silicon, with a possible increase in phosphorus, and a reduction in sulphur and manganese, will put the chemical composition right. Pouring at too low a temperature, or want of proper venting, or too wet sand, will, of course, produce "shut ends," but these are mistakes which a little care and experience should prevent.

(2) **Rough Surfaces.**—These may be due to coarseness or want of refractoriness in the sand, but are usually caused by the metal being either too hot when poured, or too hard. As hard metal is thick when melted, it requires a higher temperature to ensure fluidity, and hence leads to rough surfaces. It is for this reason that silicon contributes so much to the smoothness of surface, and freedom from sand, in a casting. As Mr Keep points out, in small castings the liberation of graphite at the surface prevents the sand from burning on; while with heavy castings the graphite is deposited under the scale, and causes it to peel off, and leave a smooth surface.

(3) **Blowholes.**—These are a constant source of trouble in some shops, while other iron-founders have very little difficulty in obtaining sound castings. The commonest cause of blowholes is deficiency of silicon, hard white sulphurous metal being particularly liable to this defect. As previously mentioned, want of proper venting, or the presence of too much moisture in the sand, is also at times responsible for blowholes.

(4) **Sponginess** or porosity is sometimes the cause of trouble, especially where the casting has to contain water under pressure. Occasionally cylinders are produced which are so porous that water, when under considerable pressure, passes through the metal sufficiently fast to form drops on the outside of the cylinder, or even to produce fine fountains of spray. Porosity is generally due to the presence of a high percentage of graphitic carbon in the special form of large

flakes, which are shown in fig. 49. When the carbon is in a finely divided state, as in fig. 52, there is usually no trouble in this respect. Porosity can be overcome by the addition of steel or wrought iron to the charge in the cupola, or by suitably adjusting the proportion of silicon. A special form of porosity is caused by contraction during cooling, in cases where there is a want of uniformity in the patterns, as shown in fig. 31. By distributing the same amount of metal in a different way, the formation of hollow portions such as are here indicated may be largely avoided.

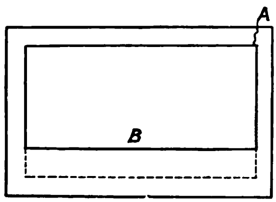
There are still two other important sources of trouble to the iron-founder, due respectively to shrinkage, and to faulty design. The causes of these defects are intimately connected, and they now demand consideration.

The iron-founder sometimes seems to run on a vein of ill-luck. His castings, though they may appear to be quite perfect when hot, will fracture with an audible sound when cooling, or develop cracks or fissures on being allowed to stand. It will usually be observed that fracture occurs at about the same part of the casting. Sometimes this happens when the pattern has not been altered, and when to all appearance the procedure is exactly the same as has been successfully adopted for weeks, or months, beforehand. Careful examination will, however, almost always show that the character of the iron has changed, and if the iron-founder is in the habit of taking shrinkage tests, he will have observed that the fractures, or "draws" above mentioned, have occurred at the time when the shrinkage of his metal was abnormally high. It must be remembered not only that high shrinkage in itself introduces additional strain in the casting, but also that metal with high shrinkage is hard, and consequently less ductile and more brittle than softer material. The usual remedy in such a case is the addition of a little more silicon to the foundry mixture; or, conversely, a reduction in the proportion of sulphur and manganese. A reduction in the proportion of scrap charged with the pig iron will not unfrequently accomplish the same purpose.

In some cases, however, draws are met with where the iron has remained constant, but the pattern has been altered. If it should be found that the iron is quite satisfactory for a certain number of patterns, while, with one or more patterns, draws appear, then it may naturally be presumed that the pattern is at fault and not the iron. Sometimes, what might appear to be perfectly harmless alterations

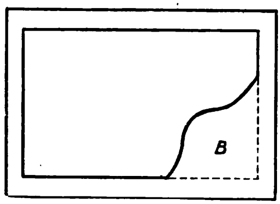
are made in the length or thickness of the patterns, so as to produce a different size, or to give additional strength. If in this way what may be called the "balance" of the pattern is interfered with, the casting is very apt to crack on cooling, even though the metal be tolerably satisfactory in composition.

In order to understand this effect it is necessary to consider the condition of a specimen of cast iron during cooling. If, for example, we consider the case of a casting in the shape of a cube of one inch square, the outside will naturally cool and become rigid more rapidly than the inside; but all the sides of the cube will be equally affected, and the result will be equal shrinkage in all directions. If, however, twelve such cubes are placed side by side so as to make a bar of twelve inches long by one inch square section, it will now be found that as the outside and ends cool more quickly than the inside and



A, fracture; B, increased thickness.

FIG. 30.—Diagram illustrating Cause of Fracture from Shrinkage.



B indicates probable position of hollow place or sponginess due to irregular thickness.

FIG. 31.--Diagram illustrating Cause of Spongy Part of Casting.

middle, contraction will take place chiefly in the direction of length. As a general rule, therefore, it will be found that the thinner the casting the greater will be the contraction of length as compared with that which takes place in other directions.

A simple illustration of the way in which fracture can be produced by altering the pattern is furnished by a rectangular casting shown in plan in fig. 30. If the original pattern, as indicated by the black and dotted lines, were satisfactory, but if for some reason the one side be increased in thickness as shown by the line B, it is probable that during cooling a fracture would take place on the thin side, or at A, because the thin side would now contract more than the thick side, and cast iron is not ductile, and does not extend under stress.

In following out the same idea, and starting from a simple pattern as shown in fig. 31, if the original uniform rectangular design be

altered from the shape as indicated by the dotted line, so as to give a large mass of metal in one part, it is probable that during cooling a hollow part or spongy portion may develop somewhere towards the centre of the larger mass of the casting (as at B), since this portion remains longer fluid. Such places are frequently met with when there is a considerable change in the thickness of the pattern.

There is yet another form of faulty design which is responsible for

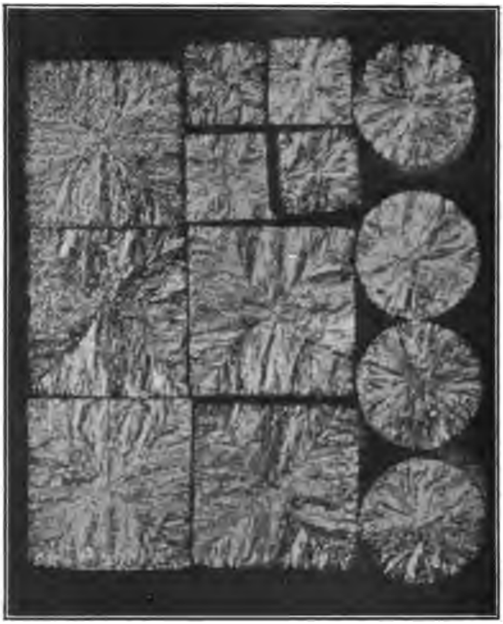


FIG. 32.—Fractures of White Cast Iron, showing crystalline structure—after Outerbridge.

weakness in iron castings, and which is connected with the crystallization of the metal during cooling. If, for example, some sulphur is melted and is poured into a mould and then allowed to cool slowly, it will be found on fracture to have developed a crystalline structure, and that the crystals have been formed at right angles to the cooling surface. Cast iron crystallizes in the octahedral system, and though its power to crystallize is not nearly so marked as in the case of sulphur, still, to some extent no doubt, the same influences are at

work, and there is evidence that, as a general rule, a crystalline structure at right angles to the cooling surface is set up in cast iron when it passes from the fluid to the solid state. This effect is most readily observed in cast iron which has been chilled, in which case a distinct crystalline character is often to be plainly seen, as illustrated in fig. 32.

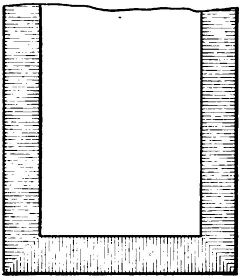


FIG. 33.—Diagram showing effect of sharp angles in a casting.

If now we consider a corner seen in the illustration given in fig. 33, it will be observed that the two sets of crystals cross on a line which bisects the angle, and where these crystals meet a plane of weakness is developed. For this reason cylinders should never be cast with flat bottoms and sharp corners, as a comparatively moderate internal pressure will often force out the bottom of such a cylinder in a single piece. In every case where strength is required, sharp corners, or sharp re-entering angles, should be avoided, and wherever possible a smooth contour adopted. There should also be no abrupt or unnecessary changes in the thickness.

Note.—In connection with this portion of the subject, two recent articles on the Foundry may be read with advantage, viz., "Modern Foundry Appliances," by Dr R. Moldenke, *Cassier's Magazine*, vol. xxiii. p. 251, and "The Equipment of the Foundry," by J. Horner, *ibid*, vol. xxiv. p. 486. Among larger works, "The Metallurgy of Cast Iron," by T. D. West, and "Modern Foundry Practice," by J. Sharp, may be consulted.

LECTURE V.

TESTS FOR CAST IRON. CHEMICAL TESTS. PHYSICAL TESTS—FLUIDITY, SHRINKAGE, HARDNESS, TRANSVERSE STRENGTH, TENACITY. THERMAL TESTS. THE MICRO-STRUCTURE OF CAST IRON.

LECTURE V.

Tests for Cast Iron.

In iron-founding, as in other trades, regularity and trustworthiness of the product are essential to success. The iron-founder should be able, if required, to continuously produce a large number of articles of regular and uniform character; or, on the other hand, should be capable of making a special article of definite strength and texture when necessary. All kinds of suggestions have been made by interested persons with the object of supplying the iron-founder with special recipes, or quack medicines; but just as there is no royal road to knowledge, so also there is no royal road to regularity. The iron-founder can only ensure uniformity by thoroughly understanding the material he is using, and regularly applying suitable tests. These tests should be quantitative in character; that is, such as can be expressed in quantities or figures. Qualitative tests may be useful at the time; but to say that a metal is "hard," or "very hard"; or that it is "fluid," or "very fluid," is of very little value for the founder's own future reference, or for the guidance of others; and until the values obtained can be expressed in figures, the iron-founder cannot claim that he has adopted any really scientific method. Only a few years ago, comparatively speaking, accurate tests were practically unknown in the iron-foundry, but recently great progress has been made.

When considering the question as to the character of the tests which should be adopted, we are at once met with the important preliminary inquiry as to what it is that we desire to test; or in other words, should the test be made upon the iron as received, or upon the casting as sold? Both systems have their defects and their advantages. It must, however, be acknowledged that it is extremely

difficult to arrange for a test on a finished casting which shall really represent its character. It is comparatively easy to test a sample of uniform material, such as mild steel, since it may be assumed that one portion of the material is very much like any other portion. But in the case of a large casting, a piece cut out from the middle is usually weaker than a piece taken from a thinner portion; while the strength of a fairly soft mixture steadily increases with a diminution in the size of the casting, so that the result of the test made upon a casting of varying thickness would depend upon the position from which the test pieces were selected. On the other hand, a test piece cast of the same metal, but in a separate mould, might be better or worse than the casting to be tested; and, even when a test piece is cast on to a larger casting, it does not necessarily follow that such a test piece will truly represent the character of the whole. Mr R. Buchanan has pointed out, in an interesting paper,[1] that the test bar is often very unsatisfactory when regarded as a real test of the product, and that the most rational plan for this purpose is to test a certain proportion of the finished castings, either to destruction, or to such a point as may be considered sufficient to ensure safety. On the other hand, testing of the cast iron as received in the foundry, though no doubt of great assistance to the iron-founder, is no guarantee to the consumer that the product will be satisfactory, as the iron may be considerably changed as a result of remelting, or it might not originally have been suitable for the size and shape of casting desired. On the whole, therefore, it would appear that the iron-founder should, for his own information and guidance, conduct tests of the metal before it is cast. These tests may be made either of the pig iron received, or of the cupola metal just before pouring a mould. But for the satisfaction of the purchaser a certain proportion of the foundry castings should also be carefully tested, either to destruction, or to some agreed point.

It must, however, be remembered that the object of the iron-founder is to make a living, and to do this he must be able to produce castings at a profit. Hence it is to his interest to discard any tests which are unnecessary, and to adopt only such as can be regularly performed without undue trouble or waste of time. He must also select those tests which are most likely to afford information as to the particular characteristics which are desired in any special case. A fairly complete scheme of tests, such as would be

[1] "The False Witness of the Test Bar," *Engineering Magazine*, 1902, page 246.

adopted in any important scientific investigation, may be classified as follows :—

(1) **Chemical Tests.**—Including sampling and the estimation of carbon, silicon, sulphur, manganese, and phosphorus, together with any other elements which may occur in quantities sufficient to appreciably affect the use of the metal for foundry purposes.

(2) **Physical Tests.**—Including fluidity, density, grain, chilling properties, and shrinkage; transverse, tensile, crushing and impact strength; hardness, and working and wearing qualities.

(3) **Thermal Tests.**—Including determination of melting points, and of volume changes depending on alterations of temperature.

(4) **Microscopical Examination.**—

These may now be considered in the above order, as fully as the limited space at our disposal will permit.

Chemical Tests.

In very large foundries, or in those which are connected with a blast furnace plant, a chemist may be regularly employed. As a general rule the founder is advised not to attempt to perform his own chemical analyses, as such determinations require considerable time and special skill. The sampling is, however, very commonly done at the foundry, and the importance of care and knowledge in this apparently very simple operation is generally overlooked. The common plan is to select a piece of a pig and send it to the analyst. This pig may not fairly represent the bulk, and no amount of care on the part of the analyst can make the results deduced from a bad sample other than misleading.

The American Foundrymen's Association recommend that eight pigs should be selected from each car load of pig iron, two each from the upper and lower portion of each half of the car. These pigs should be broken so as to give a clean fracture, and the pieces should be put in a suitable box properly marked. Each of the pieces is now drilled on the clean face of the fracture in two places, halfway between the centre and the edge, a drill of large diameter being used. The drillings are then mixed on a sheet of glazed paper, and sufficient taken to supply as many samples as may be required. In case of very dirty or sandy iron a magnet may be used on the

drillings, before analysis, for additional safety. As the cars used in the United Kingdom are smaller, half the above number of samples would probably be sufficient, in this country, to ensure equally trustworthy results. It should be remembered that the sulphur occurs in cast iron as sulphide, which appears to undergo oxidation on exposure to the air; hence drillings which have been kept for sometime give lower results than fresh drillings, if tested for sulphur by the evolution method. Both sulphur and silicon are unequally distributed in pig iron from the same cast, but they differ in the manner of variation; for while silicon is pretty evenly distributed throughout any particular pig, it varies from pig to pig in the cast; sulphur, on the other hand, is fairly equal in amount in each pig from a cast, but varies in different parts of the pig, there being a tendency to accumulate towards the centre in hematite iron, but to be found more at the outside, and top, in manganiferous irons.

The influence exerted by each element which is usually present in cast iron, and the proportions which are most suitable for particular purposes, have already been dealt with in Lecture III., and need not be here repeated.

Physical Tests.

(*a*). *Fluidity* is of special importance when thin castings have to be produced. It can be quantitatively expressed by the length to which the metal will flow in a sand mould which is of standard cross section and of a length greater than can be run full by the most fluid iron which has to be tested. Mr Keep has employed for this purpose a thin strip 1 in. $\times \frac{1}{16}$ in. $\times$ 12 in. The head of metal should of course be the same in each test. Temperature is naturally an important factor in this case, and the metal should be poured at that temperature which an experienced caster regards as the best pouring heat for the class of iron employed. If a pyrometer is used it must be remembered that the proper pouring heat is not identical for all kinds of cast iron. We have therefore the difficulty that if all irons are poured at the same temperature some do not get a fair chance, while if they are poured at different temperatures comparison is scarcely possible.

(*b*). *Density.*—This is determined in the usual way by observing the amount of water or other suitable liquid displaced by a known weight of metal. In my own experiments check determinations were made by weighing pieces of the metal in water, and also turnings

in paraffin oil. The results agreed fairly well, except with hard metal, which usually contains more blowholes, and which was therefore lighter in the larger pieces than in smaller fragments. Speaking generally, hard metal is more dense, and soft metal lighter, strong cast iron having a density of about 7·35 at 20°C. when water at the same temperature is taken as unity.

(*c*). *Grain* is the structural appearance observed on examining a freshly fractured surface. In pig iron it is expressed, as explained in Lecture II., by the grading number. In castings the grain may be observed through a double convex lens, with a focal distance of three-quarters of an inch, as suggested by Mr Keep. Such observations have, however, become less important in recent years in view of the much fuller information now supplied by photomicrography.

(*d*). *Depth of Chill.*—This is of importance where a hard surface is required. It is measured by casting a piece of suitable size with the end or side against a chill. The casting is broken when cold, and the depth of chill is measured in inches. In Keep's tests, subsequently described, the usual size of test bar is 1 foot long by ½ inch square section. These bars are cast between chills placed at each end (see fig. 34), and one end of the bar afterwards is fractured longitudinally, so as to expose the chilled portion. This is done by placing the point of a cold chisel a little behind the chilled part, when a blow from a hammer will split off a side of the bar. The depth of chill is then measured in hundredths of an inch. No. 1 iron will give no chill; iron for thin castings gives only about ⅛ in. chill; strong castings give up to half an inch; white iron is of course all chilled. For ordinary foundry work larger test pieces are generally used, such for example as 10 in. × 6 in. × 1 in., and these are fractured across the middle so that the chill and grain may be observed. In a good chilling iron the passage from white to grey should not be too abrupt; an intermediate mottled part indicates greater toughness and strength.

Shrinkage.—It is a matter of common knowledge that iron shrinks in passing from the temperature of solidification to that of the atmosphere. Consequently castings are smaller than the patterns from which they are made, and it is usual when making a pattern to allow one-eighth of an inch to the foot, or 0·125 in. in 10 in. in order to obtain the required size. It is also known that some irons shrink more than others, and that in all cases the contraction is greater in the direction of length than in that of thickness. There is, however, no property which is more easily measured, or which,

when understood, gives more important information than shrinkage. As we are indebted to Mr W. J. Keep for much accurate information, both as to the total shrinkage of cast iron, and also as to the intermediate stages by which the final result is reached, it will be necessary to give a brief outline of "Keep's Tests," and of some of the conclusions to which this method of investigation has led.

The primary idea underlying this method of testing is that it is impossible to get any size or shape of test bar which shall accurately represent the properties of the metal in the actual casting. So much depends on the grain of the iron, and this is in turn so largely dependent on the rapidity of cooling, and hence on the size of the casting, that no standard size can be adopted which shall exactly correspond with the castings which have to be produced in actual practice. For example, if a tolerably soft iron be cast in bars of decreasing size, say of 2 in., 1½ in., 1 in., ¾ in. and ½ in. square

FIG. 34.—Keep's Test Bars. Patterns, Chills, and Follow-board.

section, it will be found that the strength per unit area increases as the size decreases, even though every possible care be taken to ensure uniformity in composition and in conditions of casting.

In view of the above, Mr Keep introduced a series of tests intended to give as much information as possible as to the physical properties of the sample, and yet to be simple, rapid, inexpensive, as far as possible self-recording, and still of such a character as could be carried out without interfering with the regular routine of the foundry. For ordinary purposes the test bars employed are quite small, though for special observations larger test bars may be employed with advantage. The normal size is, however, 12 in. in length, and half an inch in square section. Two or more such bars are cast at the same time, and these allow of determinations of shrinkage, chill, transverse strength, deflection, and impact.

Returning now to shrinkage, which is the simplest and yet for many purposes the most important test, the method of operation is

briefly as follows:—For the production of the mould an iron follow-board containing brass patterns for two test bars, each 12 in. × ½ in. is employed (see fig. 34). The bars are cast horizontally, as an extended series of experiments has shown that better and more uniform results are obtained in this way than when the moulds are vertical. Iron chill blocks are placed at the end of the patterns, and the metal enters on the under side of the test bars, a skim gate being provided. The flask in which the mould is made is shown in fig. 34*a*. The mould is prepared with good quality green sand, without facing. In order to prevent rusting, the chills should be moistened before and after use with kerosene, and the patterns must not be rapped, but withdrawn so as to leave the mould the exact size of the pattern. As it will usually be desired to conduct several tests at one time, or at all events to be able to do so when necessary, several sets of chills are provided, and as these may slightly vary, they should be

FIG. 34A.—Flask for Test Bars.

marked, and a corresponding mark be made at one end of the bottom of the mould with every test.

When the bars are cast and cooled they are placed on the follow-board, with the chills, in exactly the same position as the patterns lie (see fig. 35). The taper scale shown in fig. 36 is then inserted between the end of the test bar and the chill, and the mark on the wedge, which appears just at the surface of the bar, indicates the shrinkage in hundredths of an inch per foot of casting. The measure of shrinkage so obtained is termed by Mr Keep the "Mechanical Analysis" for silicon. Such a test does not actually give the percentage of silicon, but from a practical point of view it does more than this. It gives an indication of the net softening constituents which are present, while analyses only return the hardening and softening elements, and leave the founder to draw a more or less uncertain conclusion. On the other hand, if the founder has once

determined the shrinkage which best suits his own class of work, which may be, say, 120, 130, or 140 thousandths of an inch as the case may be, he then knows at once that if his shrinkage test is higher than usual, his silicon should be increased, while, on the other hand, the silicon should be diminished if the shrinkage is less than the standard.

FIG. 35.—Measuring Shrinkage.

If it be desired to test the metal as purchased, a sufficient quantity of pig iron should be remelted in a closed crucible; but ordinarily metal is taken from the cupola in a small ladle. The moulding and casting are, of course, quite simple operations, and the measurement of shrinkage can be done in a single minute, without the slightest injury to the bar, which is still available for other tests.[1]

Transverse Tests.—The usual bar adopted in this neighbourhood

FIG. 36.—Taper Scale for Shrinkage.

for transverse tests is rectangular in cross section, the size being 2 in. × 1 in. and the supports 3 ft. apart. Convenient machines, of a simple type, are specially supplied for testing such bars. The results are expressed in cwts. and the extreme variations are from about 5 to 45. Common irons give about 20 cwts. with such a test bar, while for better class castings 30 cwts. is specified, and 40 cwts. and upwards can be exceptionally obtained. Sometimes, too, a time test is specified, the bar being loaded for 24 hours with 20 cwts., and afterwards tested to destruction, and no doubt such tests give additional security to the engineer. It is observed that bars cast at a higher temperature usually give better tests than usual, and this

[1] Mr T. D. West distinguishes between "shrinkage" and "contraction," the former being used when the metal is still fluid and the casting has to be "fed," and the latter when the iron has solidified and is cooling to atmospheric temperature. *Amer. Inst. Mining Engs.*, Feb. 1896.

should be borne in mind by those who wish to obtain an honest result. It is perhaps unnecessary to refer to tricks, such as the addition of steel turnings, which are resorted to by unprincipled men when test bars are required for purposes of inspection.

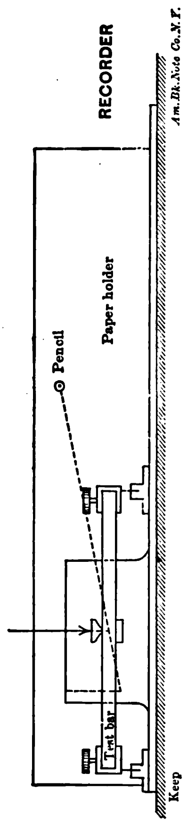


FIG. 37.—Transverse Testing Machine and Recorder. Outline.

FIG. 38.—Keep's Transverse Testing Machine.

In Keep's tests transverse strength is measured on the 12 in. by $\frac{1}{2}$ in. bar in a special machine, which is diagrammatically represented in fig. 37. The bar is fastened, with the gate mark underneath, in

flexible end bearings, and the weight is applied in the centre of the top of the bar. A sheet of paper is placed behind the test piece, and is automatically moved as the weight is added. At the same time, by means of a pointer, the deflection of the bar is multiplied fivefold, and the result of the double motion is the production of an automatic record of the deflection, which is of value as indicating the stiffness or brittleness of the bar. A machine of full size for scientific purposes, and capable of testing bars up to 24 in. by 1 in. square section, is shown in fig. 38.

The ductility of cast iron is so small as to be usually almost inappreciable by ordinary tests. The deflection test, however, indicates considerable differences with irons of varying character. In a ductile material under transverse test the upper portion of the bar is in compression while the lower part is in tension. A high transverse test therefore indicates combined crushing and transverse strength, and no doubt this is the reason why transverse tests are so much in favour with chilled roll makers and others who require a strong close grained iron capable of resisting shocks. For softer material I have found tensile tests give very satisfactory results.

Tensile, Crushing, and Impact Tests are chiefly adopted by engineers, or in connection with engineering establishments, where facilities exist for conducting similar tests on other materials. The size and shape of the test pieces adopted varies considerably, the important point to be remembered being that on account of the very small ductility of cast iron, any want of directness in the pull with the tensile machine, or want of fair bedding in the crushing test, will lead to low and irregular results. Small variations of this kind, which would be without appreciable result in testing mild steel, would quite vitiate the value of a test as applied to cast iron. For impact tests Mr Keep employs bars of the usual size, which are broken in a special machine by blows from a swinging weight of 100 lbs. There is a curious fact in reference to impact tests which was discovered by Mr A. E. Outerbridge, and confirmed by Mr Keep, namely, that bars which have been smoothed on the surface by blows from a hammer, or which have been tumbled in a tumbling-barrel, are stronger than companion bars which have not been so treated. There is also a slight alteration in length under such treatment, which points to some rearrangement of the particles, and a relief of a condition of strain which exists in the original castings. (See Keep's *Cast Iron*, p. 153, and note on p. 131.)

The tensile strength of cast iron usually varies from about 4 to 16 tons per square inch; the average for common iron is about 7 tons, while for selected brands about 11 tons is a fair value. Several cases are on record where a tensile strength of upwards of 20 tons, per square inch has been obtained with cast iron. Professor Ledebur is in favour of tensile tests for cast iron, and my own experience has been that where a complete system of testing cannot be applied, no other test gives more satisfactory results. The average crushing strength of cast iron is about 40 tons per square inch; 60 tons can be regularly produced if required, while upwards of 95 tons per square inch has been recorded. Further particulars and details of tensile and crushing tests are given in my *Metallurgy of Iron*, p. 234 *et seq.*, and these may be consulted by those specially interested in this branch of the subject.

Hardness of Cast Iron.—There are few properties of a metal which are, in actual practice, more important than its hardness; yet there are few properties which are so little understood or so seldom quantitatively measured.[1] It is almost more important to determine what is to be measured than how it is to be done, since hardness is so commonly confused with tenacity, brittleness, and "workability." Hardness may be defined as the property which enables a substance to resist penetration by another body; or in practice as the resistance to a cutting tool. In tests of hardness in which a cut of appreciable depth is taken, the metal is torn asunder and tenacity comes into question. In tests of another kind, where an indentation is produced, both tenacity and ductility play important parts in determining the result. In grinding tests the softest metal may clog the grinding surface, so that a harder material will grind more quickly. Theoretically I regard the mineralogical test as being the best for the determination of what may be called true hardness, and upon this method the instrument used in my own researches, called a sclerometer, is based. This apparatus is shown in fig. 39, and consists essentially of a diamond point fixed at the end of a balanced arm, and arranged so as to be drawn over the smooth

[1] See the Author on "Hardness of Metals," *Chem. News*, vol. lv. pp. 179 et seq. M. F. Osmond, Reports (in French) on "Hardness; its Definition and Measure," and "Tests by Penetration and by Scratching," presented to the Commission des Méthodes d'Essai des Matériaux de Construction, Paris, 1892. Also Brinell's "Method of Determining Hardness," *Journ. I. and S. Inst.*, 1901, vol. i. p. 243; vol. ii. p. 234.

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horizontal surface of the piece of metal or other material to be tested. The weight in grams required to produce a standard scratch is taken as the measure of the hardness of the substance. The hardness of cast iron, as thus measured, varies from about 22 to 72, and the results agree with the observations of a skilled workman. It is found that metal of high tensile strength, specially suited for engineers' purposes, is always soft good working material, while very hard metal is, conversely, deficient in strength.

Keep's Hardness Machine.—From the practical point of view the sclerometer has certain disadvantages which have prevented its more general adoption. In the first place, the record is not autographic, and some special skill is required in determining the standard seratch. Further, only the outside of the sample is tested, and the interior may

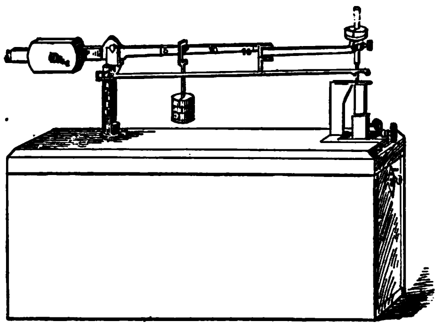

FIG. 39.—Turner's Sclerometer.

be quite different in character, though this difficulty may frequently be surmounted by the use of sufficient samples properly selected. Many other forms of apparatus have been suggested; of these one, which is of special interest to the iron-founder, has been introduced by Mr Keep, and is represented in fig. 40. With this apparatus the object is to measure the workability of the metal, and to obtain an automatic record from a test conducted through a determined thickness. The apparatus consists essentially of three parts—

(*a*). A standard $\frac{3}{8}$-in. drill, working at 200 revolutions per minute, and arranged so as to enter the test piece from below and drill upwards. A tray is provided into which the drillings fall if they are required for analytical purposes.

(*b*). A table to which the test piece is clamped. This table may be raised or lowered, as desired, by the hand wheel at the top of

the machine. From the table is suspended by means of four rods a weight which is adjusted so that the total weight on the drill point is 150 lbs., including the weight of the test piece.

(*c*). An autographic recorder consisting of a curved paper-holder, upon which moves a pencil which is connected with the table with steel ribbons and a ball bearing arm.

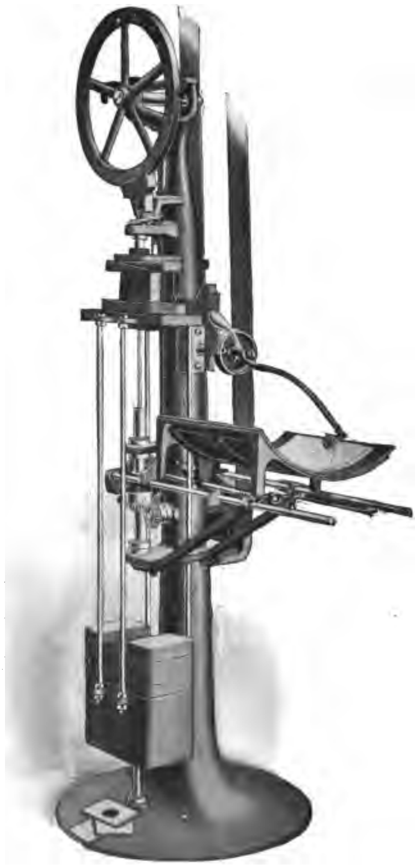

FIG. 40.—Keep's Hardness Testing Machine.

Briefly, therefore, the automatic record is that of a standard drill pressed with a weight of 150 lbs. and making 200 revolutions per minute. A diagram taken from Mr Keep's *Cast Iron* will serve to illustrate the character of the results obtained (fig. 41). The record of hardness is a line lying between 0° and 90°, the former being a material perfectly soft, such as a liquid; and the latter a substance too hard to be cut with the steel drill. In the diagram on the left, the bar used (which was ½-in. square in each case) had two hard spots, one of which was too hard for the drill to penetrate. The hard portions are indicated by the more vertical direction of the line. In the middle diagram, on the other hand, the drill during its course passed through a spongy part towards the centre of the bar. The line on the right is from a metal of uniform character and moderate hardness.

Mr Keep is careful to point out that such tests do not distinguish between hardness and tenacity. At the same time, by whatever name the property which is measured is called, it is one which is of the greatest possible importance in practice. For want of a better term it may be called workability. In some cases where the wearing power of cast iron has to be tested, blocks of the metal under test are attached to some portion of the machinery which is in regular motion, and are thus caused to rub backwards and forwards, under definite pressure, for a determined number of times—the number being hundreds of thousands or millions if

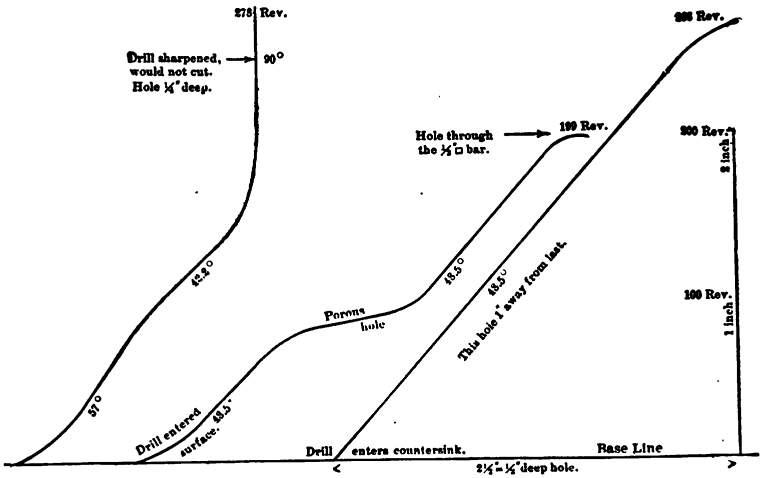

FIG. 41.—Keep's Hardness-Machine Diagram.

necessary. Such a test takes several weeks to carry out satisfactorily, but is stated to give excellent results.

Thermal Tests.

Melting Points.—It is known that the melting point of cast iron varies according to its composition, some varieties requiring about 200° C. higher temperature than others. The iron-founder would, however, not attempt to make tests of this description himself except in very special cases, as, for example, where a suitable pyrometer is used for other purposes in the establishment. A form of instrument which can be recommended for the purpose is the thermo-electric pyrometer of H. Le Chatelier, with an automatic recording attach-

ment, such as the photographic recorder introduced and used with such brilliant results by the late Sir W. Roberts-Austen.[1]

Volume Changes due to Temperature.—To Mr Keep we are also indebted for much valuable information in relation to the changes which take place during the cooling of cast iron from the moment of solidification until it reaches the ordinary temperature of the foundry. In connection with these researches a special form of apparatus was employed for automatically recording the expansion or contraction which takes place during the cooling of a bar of cast iron after it has commenced to solidify. For this purpose the casting is made in sand, in a special box (see fig. 42), and two steel pins are placed in the mould at a fixed distance apart. As the metal cools these pins move inwards or outwards, and their motion, when

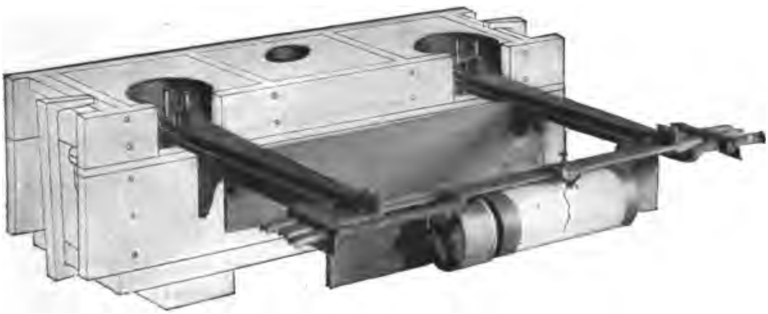

FIG. 42.—Keep's Cooling Curve Recorder.

magnified, is communicated to the point of a pencil which moves on the surface of a sheet of paper fixed on a rotating cylinder. In this way autographic records can be readily obtained. In examining the record obtained from metals such as tin, lead, or copper, it will be found that the curve is a uniform one, due to the regular contraction of the metal from the temperature of solidification to that of the air (see fig. 43). With cast iron, however, the shape of the curve is quite different. White cast iron behaves more or less like the metals previously mentioned, the deviations from the regular form of the curve being relatively small; but with grey cast iron there are definite points of arrest in the shrinkage, and at these points actual expansion takes place. The character and amount of the expansion varies with the composition of the iron to be tested. Speaking

[1] *Introduction to Metallurgy*, 5th edit., p. 194.

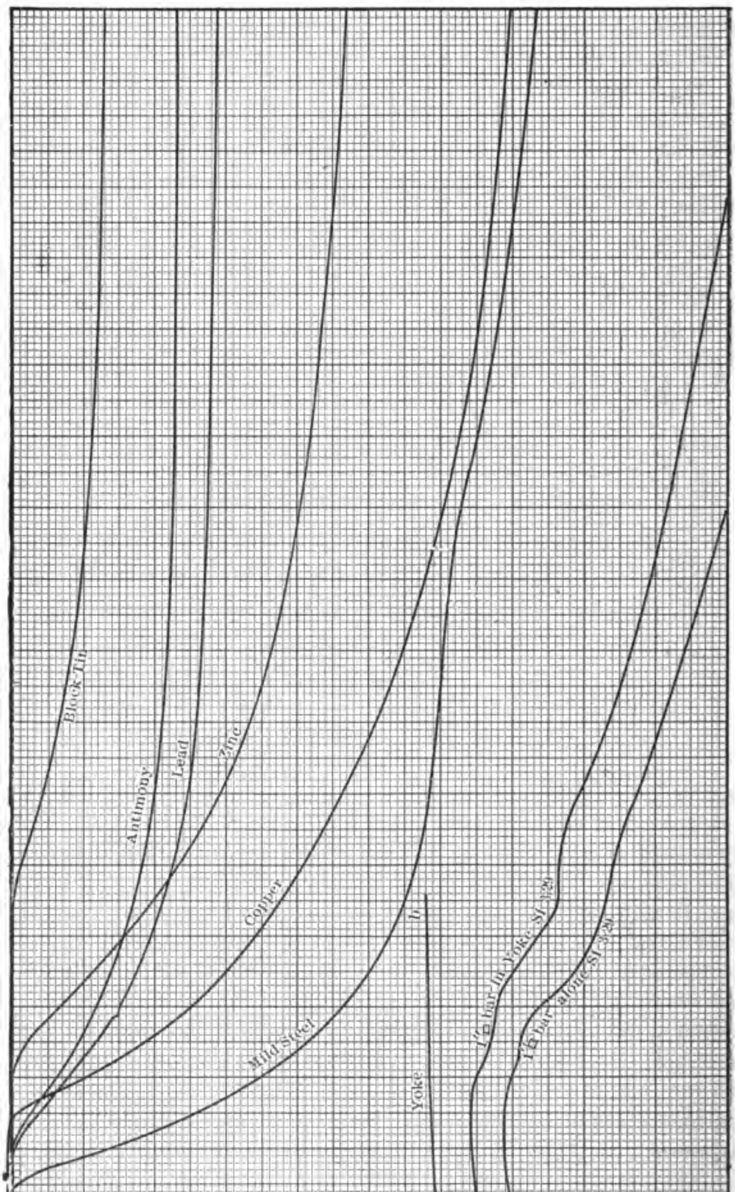

FIG. 43.—Cooling Curves of Common Metals, etc.

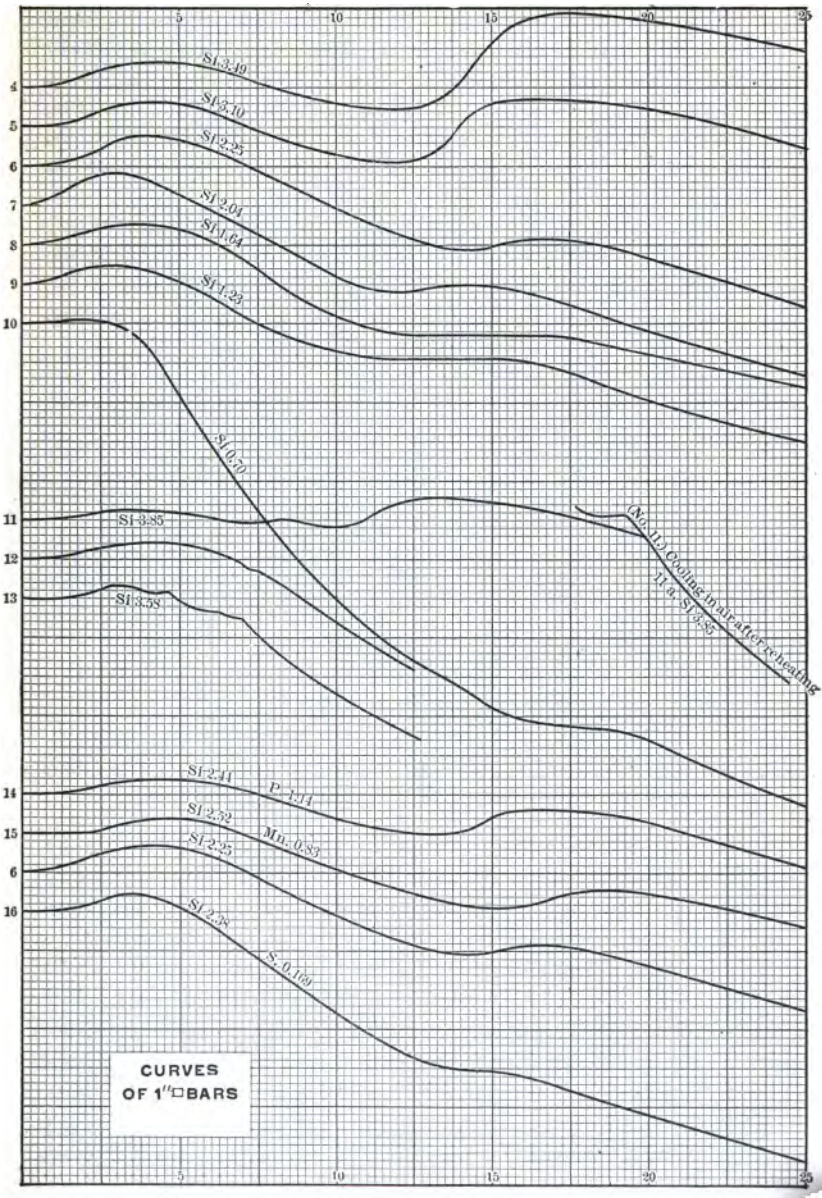

FIG. 44.—Cooling Curves of Cast Iron with different Proportions of Silicon.

generally, the greyer the iron, and the richer in silicon, the more pronounced is the expansion. In very grey iron there are usually three separate expansions noted. This is illustrated in fig. 44, in which are given a number of autographic records of iron with varying proportions of silicon. These expansions no doubt account for the well-known fact that soft iron does not contract during cooling as much as white or harder metal.[1]

A point about these experiments which is particularly interesting is that Mr Keep has definitely proved that the separation of graphite is not completed when the metal first assumes the solid state; but that such separation continues while the solid metal is cooling.

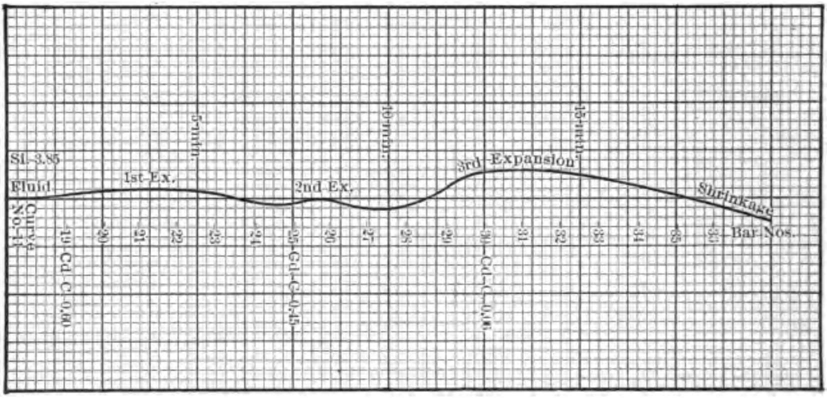

Fig. 45.—Cooling Curves from Grey Cast Iron. Showing three expansions, and diminution in combined carbon, on cooling from the point of solidification.

This was proved by casting a suitable number of samples side by side, and quenching them, one after the other, in cold water, at regular intervals of time, so as to ascertain the condition at varying stages during the cooling process. It was then found that the percentage of combined carbon in the series diminished from 0·60 before the first expansion, to 0·06 when the third expansion had taken place. This is illustrated in the special diagram given in fig. 45. The temperatures corresponding to these expansions were not determined, but the bar after the third, or last, expansion was still quite visibly red hot.

[1] For a summary of these experiments, see Keep's *Cast Iron* (Chapman and Hall), a book which can be recommended to the careful perusal of every foundryman.

It may be mentioned that Mr O. F. Hudson has, at my suggestion, recently conducted some experiments with cast iron, and has observed that the cooling curve for No. 1 Northampton grey pig iron shows three distinct points of retardation at temperatures of about 1115°, 955°, and 860° C. These curves were, by the kind

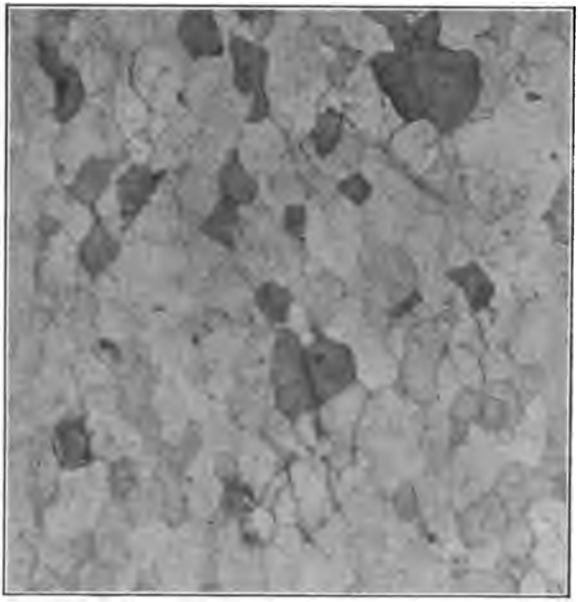

FIG. 46.—Pure Iron. Magnification, 75 diameters. Ferrite. The dark areas are due to reflection; they appear light on rotating the specimen.

permission of Dr T. K. Rose, taken in the laboratory of the Royal Mint.

The Micro-Structure of Cast Iron.

The application of the microscope to the testing of iron and steel is due to Sorby; later workers, such as Arnold, Osmond, Roberts-Austen, Stead, and Sauveur, have done much to extend and improve our knowledge of this important branch of metallurgy. The samples which are to be examined are first very carefully prepared by smoothing the surface with a fine file or emery wheel, polishing with very fine emery or rouge, and etching with nitric acid of 1·2 density,

or with some other agent which attacks the different constituents unequally. The etched surface is finally washed, dried, and examined. The usual range of magnification is from about 40 to 1000 diameters, and the light is reflected from the surface, generally in a vertical direction. For cast iron a magnification of about 50 diameters is suitable, as this shows the structure with sufficient clearness for all ordinary purposes, without being too detailed; a higher power is necessary in order to bring out the characteristic structure of pearlite. The accompanying photographs, which have been prepared for me, in the laboratory of the University of Bir-

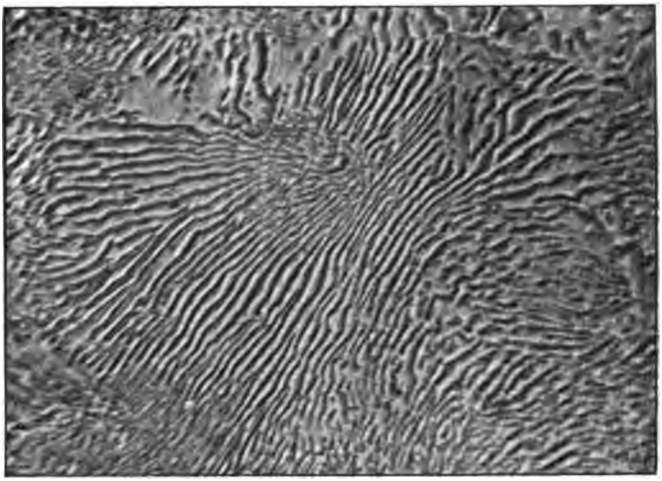

FIG. 47.—Pearlite, 1000 diameters (Osmond).

mingham, by my colleague Mr O. F. Hudson, will serve to make clear some general principles.

Special attention has been devoted by metallographists to the study of steel, and partly from this reason it may be convenient to regard white cast iron as a highly carburized cast steel. It is found on examining a prepared surface of pure iron that a characteristic cellular structure is obtained (see fig. 46), to which the name "ferrite" has been given. With gradually increasing proportions of carbon, dark-coloured portions are observed near the edges of the ferrite crystals, and these dark parts gradually increase in area until, with about 0·9 per cent. of carbon in ordinary unhardened steel, the

whole field is covered with the dark-coloured substance. This, when much more highly magnified, is found to be made up of alternate bright and dark portions (see fig. 47), which with reflected light can be made to yield a pearly lustre, and to which the name of "pearlite" is applied. This pearlite is the solidified eutectic mixture of pure iron and carbide of iron, and contains, as before mentioned

Fig. 48.—Specially Pure White Cast Iron. Magnification, 75 diameters. A hard brittle material, prepared by heating wrought iron with charcoal. Shows pearlite (dark) and cementite (light). In this case the pearlitic areas are large. Composition as follows:—

Total Carbon (combined) . . .	2·25 per cent.
Silicon	·07 ,,
Phosphorus	·06 ,,
Manganese	·05 ,,
Sulphur	·03 ,,

about 0·9 per cent. of carbon. With more carbon a uniform bright substance appears to separate out of the mass in vein-like portions, which gradually increase as the carbon rises, until this carbide, or, as it is called, "cementite," is seen to form the real ground base from which more or less pearlite has been separated (see fig. 48). With

[illegible] different constituents [illegible] washed, dried, and ex- [illegible] about 40 to 1000 [illegible] surface, generally in a [illegible] magnification of about 50 [illegible] structure with sufficient [illegible] being too detailed; a [illegible] the characteristic [illegible] photographs, which have [illegible] of the University of Bir-

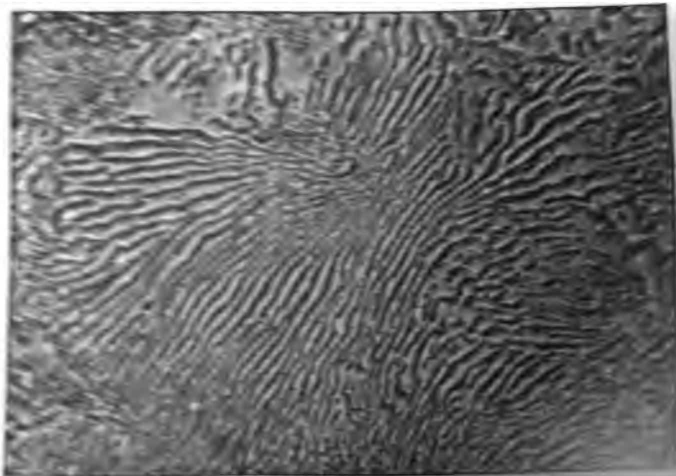

FIG. 47.—Pearlite, 1000 diameters (Osmond).

mingham, by my colleague Mr O. F. Hudson, will [illegible] clear some general principles.

Special attention has been [illegible] study of steel, and [illegible] regard white cast [illegible] on examining a [illegible] cellular structure [illegible] has been given [illegible] dark-coloured [illegible] crystals, and [illegible] about [illegible]

aphite.
variety;
rwise is
soft and
ig iron,
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Magnification, 75 diameters. Polished
coarse-grained graphite. A soft, weak

2·70		
·10		
	2·80	per cent.
	3·84	,,
	1·26	,,
	·66	,,
	·05	,,

Here the coarse-grained graphite is again quite
in large distinctive plates. Surrounding the
containing silicon; while in the more central

some 2 per cent. and upward of carbon we have this characteristic white iron structure, which consists of a white ground-work of cementite, upon which is very plainly marked a dark more or less fern-like pattern of pearlite.

The appearances observed with grey cast iron are, as might be anticipated, not merely quite different from what is seen in steel, or

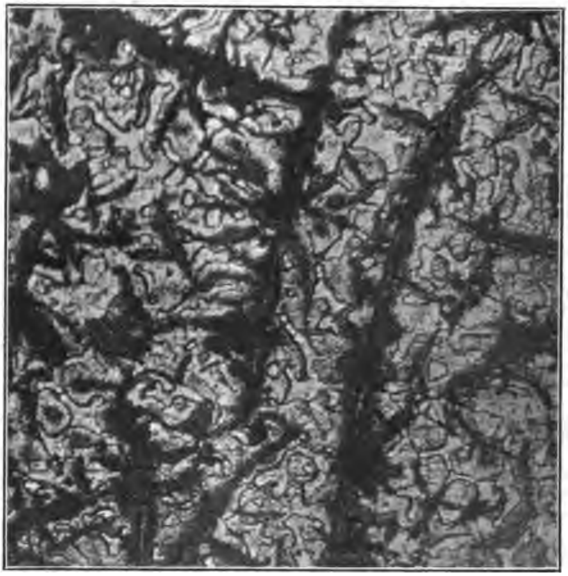

FIG. 49.—Swedish Grey Pig Iron. Fl.M. brand, used by Mr W. J. Keep in his experiments. Magnification about 75 diameters. Shows coarse-grained graphite; a soft and relatively weak iron of the following composition:—

Graphitic Carbon	3·22	
Combined Carbon	·33	
		3·55 per cent.
Silicon		1·25 ,,
Phosphorus		·08 ,,
Manganese		·09 ,,
Sulphur		·04 ,,

in white cast iron, but there are also very marked differences in various kinds of grey iron. Examining first a specially pure grey iron, the Swedish Fl.M. brand used by Mr W. J. Keep as the base in his important series of experiments, we find (fig. 49) that the metal

is intersected by dense black curved lines of separated graphite. This graphite is of what we have termed the coarse-grained variety; the metal itself contains 1·25 per cent. of silicon, but otherwise is nearly pure iron, and the material as a whole is relatively soft and weak. Turning next to a sample of a much less pure pig iron, containing phosphorus and silicon (fig. 50), we have a markedly

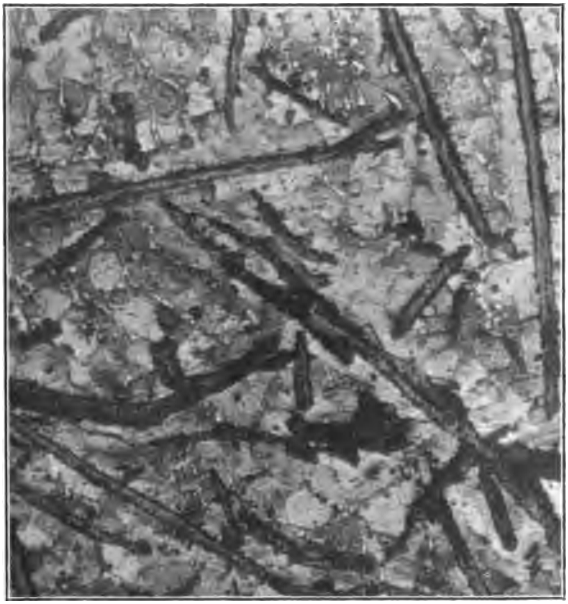

FIG. 50.—No. 2 Northampton Pig Iron. Magnification, 75 diameters. Polished and deeply etched so as to show the coarse-grained graphite. A soft, weak iron of the following composition:—

Graphitic Carbon	2·70	
Combined Carbon	·10	
		2·80 per cent.
Silicon		3·84 ,,
Phosphorus		1·26 ,,
Manganese		·66 ,,
Sulphur		·05 ,,

different structure. Here the coarse-grained graphite is again quite evident, and exists in large distinctive plates. Surrounding the graphite is the iron containing silicon; while in the more central

portions of each area enclosed by graphite will be seen, faintly outlined, the phosphorus eutectic. This is more plainly seen in fig. 51, which is a sample of the same iron, but etched so as to show the phosphoric portion. This will be seen in the centre of each area as a white portion, which no doubt separated out last, and which consists of the hard, brittle, phosphorus eutectic. This sample as a whole is a soft fluid iron, which is, however, wanting in toughness and

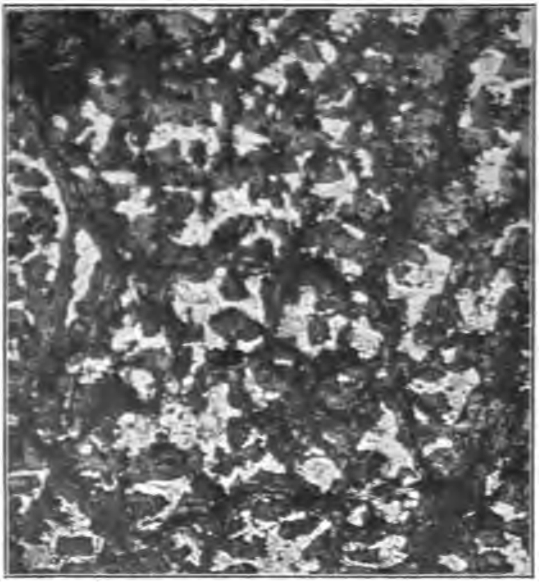

FIG. 51.—No. 2 Northampton Pig Iron. Magnification, 75 diameters. More lightly etched, so as to show the separation of the more fusible and brittle phosphorus eutectic—the light part in the photo-micrograph.

strength owing to the large size of the graphite and to the proportion of phosphorus which is present. It is not easy, at present, to recognise silicon under the microscope, and in connection with this subject we have experiments in progress. Turning now to the next of these micro-photographs (fig. 52), it will be at once seen that the appearance is altogether different from any of the preceding; the structure being much more uniform, and the graphite much smaller and less defined. This sample is representative of a material which

is almost ideal for many purposes of the iron-founder. It is a portion of a test bar, prepared in my experiments in 1884, which yielded the highest tensile strength (15·7 tons per sq. inch) of the whole series. It was a close-grained, sound, soft, tough iron. It will be seen that the graphite was in a state of fine division and

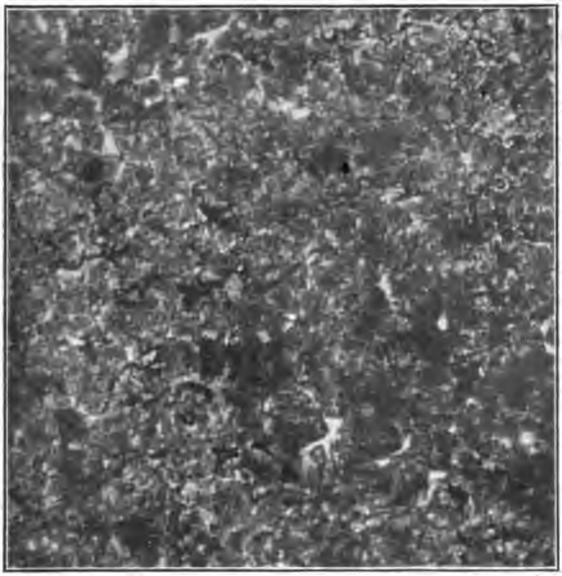

FIG 52.—Specially Strong Soft Iron. Magnification, 75 diameters. This sample was prepared in 1884 in connection with the author's experiments on silicon in cast iron. It gave the maximum tensile strength of the series (15·7 tons per sq. in.). It shows uniformly distributed, fine-grained, graphite, with some cementite. Its composition was as follows:—

Graphitic Carbon	1·62	
Combined Carbon	·56	
		2·18 per cent.
Silicon		1·96 ,,
Phosphorus		·28 ,,
Manganese		·60 ,,
Sulphur		·03 ,,

uniformly distributed, corresponding to the temper graphite obtained in malleable cast iron (see fig. 53). No doubt to this fact, in great part, the excellent properties of the metal were due. The relatively

high combined carbon also imparts a somewhat steely character to the sample, and it may be mentioned that under a higher magnification pearlite is plainly discernible.

The examples which have been given will serve to illustrate the

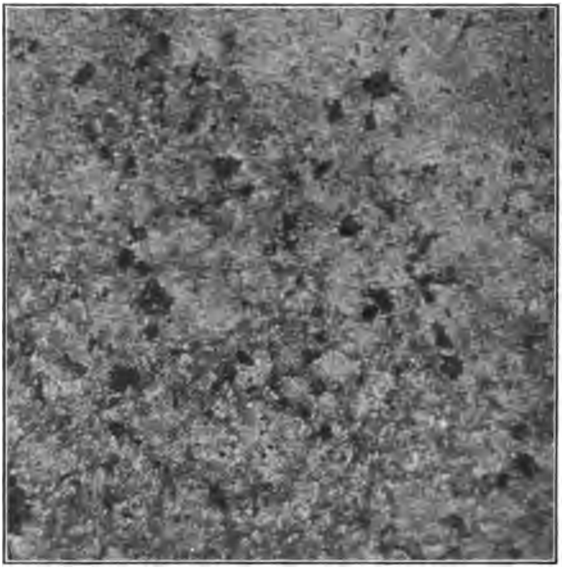

FIG. 53.—Malleable Cast Iron. Magnification, 75 diameters. Showing temper graphite ; finely divided and pretty evenly distributed.

general character of the microscopic method of testing as applied to cast iron, and will enable those who have not yet had experience of this line of investigation to appreciate how important such observations may become to the practical man.

NOTE ON THE CONDITION OF GRAPHITE IN CAST IRON.

The conditions under which graphite separates from cast iron have been recently studied by Charpy and Grenet[1] from the point of view of the equilibrium of iron-carbon systems. In these experiments white cast iron, free from graphite, was prepared by taking the purest material available, so far as elements other than carbon and silicon are concerned. This metal was cooled in cold water so as to be quite free from graphite. It was then heated to ascertained temperatures for varying periods. The conclusions arrived at were, that as the proportion of silicon increases, the temperature at which graphite separates decreases; that when separation has once begun at a given temperature it may continue at a lower temperature; that when graphite is separated at a constant temperature the rate of separation is greater at high than at low temperatures, and greater also with more silicon. It was also concluded that the amount of combined carbon which corresponds to equilibrium at a given temperature diminishes as the portion of silicon increases. In these experiments two critical points were determined for heating white cast iron, namely, about 1,150°C., which is believed to be due to the re-solution of Martensite (though if this be Martensite-graphite or Martensite-cementite appears to the authors to be doubtful), and about 700° C., which is believed to be due to the re-solution of pearlite.

Professor Howe[2] has also recently, in a very suggestive and thoughtful manner, discussed the conditions under which graphite separates from cast iron, and this may be read with advantage by those desirous of further information on the theory of the subject.

My own views on the separation of graphite may be briefly summarized as follows:—At the moment of solidification of grey iron graphite separates, chiefly in flakes or scales, which give openness of grain and softness of texture. At lower temperatures carbon separates, chiefly as finely divided, or temper graphite, which gives

[1] *Bulletin de la Société d'Encouragement*, March, 1902. '*Engineering*,' Vol. 73, p. 626.

[2] *Iron, Steel, and other Alloys*, p. 276 *et seq.*

softness, combined with closeness of texture and strength. All strong irons contain a considerable proportion of temper graphite, as is seen in the photo-micrograph of the strongest iron (15·7 tons tensile) obtained in my silicon experiments of 1885 (see fig. 52). Silicon, in due proportion, not merely leads to the separation of graphite, but of graphite in the temper form, and hence to the production of strong iron. This separation takes place after the metal is solid, but while it is sufficiently plastic to allow of expansion by the extruded graphite; or while, in other words, it is in the semi-solid state.

Hitherto there has been no method in use for the determination of the size of the graphite in cast iron, though this is a very important question in connection with the strength and working properties of the material. A great deal of information on this point can be obtained by the use of the microscope, and by the comparison of a number of samples of known composition and properties under the same magnification. In this way the eye rapidly becomes trained to recognise the different kinds of graphite, and the observer can at once distinguish a hard iron from a soft one, or a weak from a strong. Photographs illustrating characteristic varieties of graphite in cast iron have already been given at the end of Lecture V.

I have also found it possible to quantitatively separate graphite by sieving. For this purpose about 250 grams of the pig iron to be tested are taken in the form of small lumps, and repeatedly extracted with hydrochloric acid so long as any iron dissolves. The residue is then oxidized with hot dilute nitric acid, washed and extracted with caustic potash, and the treatment with acid and potash repeated as long as any silica is removed. When using such a large quantity the process is somewhat tedious, but ultimately very pure graphite is obtained, which should be dried at 120° C. and weighed. The weight so obtained corresponds very nearly with the percentage of graphite as found by combustion. The dry graphite, which usually weighs from about 6 to 8 grams, is now introduced into a set of box sieves containing 30, 60, and 90 mesh; it is thus, almost instantly, and without loss, separated into four portions, viz., the coarse, which remains upon the 30 sieve; two intermediate varieties remaining on the 60 and 90 sieves respectively; and the finer portion, which passes through the 90 sieve. This last may again, if desired, be further sub-divided.

Pure graphite, when separated in this way, is a very pretty and

interesting substance. The following figures give the results of a mechanical analysis of graphite from No. 1 Northampton pig iron, from which it will be seen that the greater part of the graphite is too coarse to pass through the 60 sieve :—

	Per cent. of Original Pig.	Per cent. of total Graphite.
Graphite left on 30 sieve . . .	·83	27·6
,, 60 ,, . . .	1·37	45·5
,, 90 ,, . . .	·28	9·3
Passed through 90 ,, . . .	·53	17·6
	3·01	100·0

If a very close grained iron be similarly treated, the greater part of the graphite will pass through the 90 sieve. It may be interesting here to note that the graphitic carbon obtained from cold blast pig iron is smaller than that obtained from ordinary hot blast varieties, and this fact very probably accounts for the closeness of texture and consequent greater value of cold blast iron.

NOTE ON THE EXPANSIONS OF CAST IRON.

Mr A. E. Outerbridge has continued his researches (see p. 112), and has published a paper on the "Mobility of Molecules in Cast Iron" in the *Transactions of the Amer. Inst. of Mining Engineers*, Feb. 1904, which confirms his previous observations that cast iron bars which have been subjected to repeated shocks or blows are materially strengthened thereby. A committee appointed by the Franklin Institute to investigate this subject reported, after testing eighty-two bars, that there was a maximum increase of strength of no less than 40 per cent. Outerbridge has also observed that cast iron bars which have been heated to about 1450° F. (790° C.), and afterwards cooled, are permanently expanded, and that this expansion is increased by repeated heatings. In fact, in certain cases, with repeated treatment, an increase in volume of as much as 40 per cent. has been obtained. All grades of cast iron do not expand equally ; varieties with little combined carbon increase more in cubic capacity than

white iron, in which the expansion due to heating is not sufficient to overcome the original shrinkage. Wrought iron and steel, if repeatedly heated in a similar manner, while protected from oxidation, slightly contract in cubical dimensions. The expansion in grey cast iron, caused by repeated heating, is due, in part at least, to the formation of minute spaces or cavities through which air can pass, and into which water can enter.

THE END

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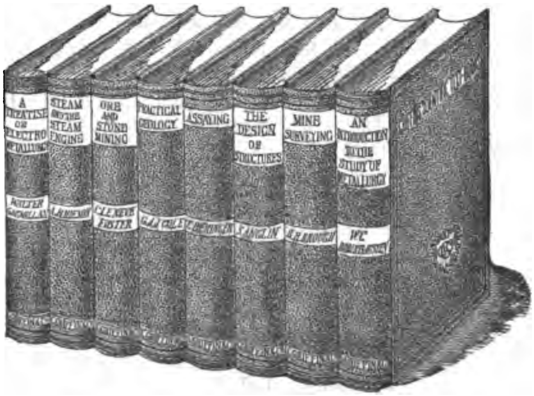

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